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Integrated Energy Systems, Inc.
Chapel Hill, NC

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SURVEY AND ANALYSIS OF CURRENT EUROPEAN TECHNOLOGIES FOR WOOD COMBUSTION

by

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ABSTRACT

This report presents a summary of current technologies and air pollution policies pertaining to wood combustion. Twenty different concepts for wood burning equipment are described. Also included are section diagrams, size ranges, and comments regarding efficiency and convenience. Many of the system types are not currently available on the U.S. market. A list of manufacturers and their addresses is included. The report also contains emission data for many of the systems described. Emission regulations and test procedures are presented. Finally, a brief overview of health research related to suspected carcinogenic materials in wood combustion emissions is presented. This information was gathered both in the U.S. and in Europe by engineers familiar with wood combustion on both continents. The work was funded by EPA's Industrial Environmental Research Laboratory to supplement their other activities relating to air pollution from wood combustion.

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EXECUTIVE SUMMARY

Unlike in the U.S., wood has not seen a dramatic increase in use as a fuel in recent years in Europe. Rather, it has always been an important fuel for certain applications. This long history combined with the relative scarcity of wood has resulted in a wide variety of efficient wood burning equipment on the European market. Some of the systems are not presently available in the U.S.

This report examines 20 different wood firing systems. Their operation is described and displayed graphically. Typical manufacturers are listed and comments are made regarding their efficiency, ease of operation, and applications. Pollutant emission data is presented for all system types. Finally, specific regulations and supporting health research are briefly discussed.

Trends in European fuel wood use for the most part are a continuation of previous applications. Only in Sweden is there strong encouragement for increased wood combustion. This is manifest in the recent construction of several wood fired district heating plants in Sweden. Elsewhere wood continues to be an important fuel in rural areas where it is often burned with coal. Wood related industries such as cabinet shops, furniture and pulp and paper are the prime consumers of waste wood. They too, often supplement the wood with coal. Another interesting trend is found in urban/suburban areas where multi-fuel boilers have become popular. The unique aspect of this is that wood is seen as an auxiliary, emergency fuel to backup oil or gas.

In the residential and small commercial market down- and cross-draft units have displaced up-drafters. Thermal storage in masonry or water has also become relatively common. Industrial wood combustion equipment appears to be moving toward cyclone burners and fluidized bed combustors. Several companies have gasifiers in the pilot stage. The main emphasis appears to be to use the gas to fire internal combustion engines, often to generate electricity.

Emission regulations tend to be simple and not particularly stringent. Great emphasis is placed on enforcement. Probably the most remarkable aspect of the pollution control strategies is the requirement of regular inspection and maintenance by licensed

chimney sweeps and other technicians. This policy has resulted not only in decreased emission but in improved efficiency and safety. Boilers must be inspected and tested annually. Those failing must undergo the required adjustments to be certified. Through the inspection/maintenance program the user gains an understanding of the equipment and its proper operation. This may be as valuable as the adjustments.

As in the U.S., equipment manufacturers strenously oppose emission standards. Their main contention is that to meet any standard the equipment must be designed for a very specific type of fuel when in fact the consumer demands versatility. In Switzerland and West Germany, multi-fuel boilers have outsold single fuel gas or oil boilers for the past five years. This flexibility in fuel types usually results in a decrease in overall efficieny.

Since wood is relatively scarce, European officials do not appear particularly concerned about emisisons from wood combustion. With the exception of Sweden, research on health effects of Polycyclic Organic Matter (POM) and Polycyclic Aromatic Hydrocarbons (PAH) have been aimed at auto and industrial emissions and occupational exposure rather than at wood combustion. The Swedish have done some research specifically on PAH emissions from wood heaters. Unfortunately, their results were inconclusive.

1.0 INTRODUCTION

1.1 PURPOSE OF STUDY

Having been involved in the design and installation of wood fired systems both in Europe and the U.S., the authors were aware of many important differences in available equipment. Some concepts found in European wood combustion systems have not yet appeared in the U.S. market, others are applied in different ways. Similarly, there are interesting differences in the approach to air pollution problems caused by wood combustion. The purpose of this report is to present an up-to-date overview of the important European technologies for wood combustion and the relevant emission data and regulations. This report supplements the activities of EPA-IERL in examining emissions and combustion technologies of residential wood stoves.

The equipment is grouped according to use; residential, commercial, industrial. For each system the combustion concept is described and shown in a diagram. These are followed by discussions of applications, fuel types and efficiency. Typical manufacturers are listed with addresses in Appendix D.

1.2 METHOD OF STUDY

American and European air pollution literature was first searched for work on emissions from wood combustion. From this an address list was started. To this list were added names of European firms with whom the authors were familiar. Finally, names of persons in various regulatory agencies were added from the author's files.

An introductory letter was sent (Appendix B) followed by a phone call from Europe. During that call exact arrangements were made for one of the authors to visit the site, gather data, and take photos. In addition, advice was sought regarding other potentially interesting researchers, manufacturers, or installations. During a period of four weeks over twenty sites in Switzerland, Germany, Denmark and Sweden were visited (Appendix C). Back in the U.S., the data and information were cataloged and letters were sent to obtain other needed information. Descriptions from literature along with site photos were used to prepare the cross-sectional diagrams presented here.

1.3 TRENDS IN EUROPEAN WOOD COMBUSTION

As in the U.S., the use of wood as a fuel in Europe declined steadily from 1900-1973. The notable exception to this occurred during World War II when wood was relied upon to run many factories, heat homes, and even to power vehicles. Prior to 1965 coal provided over a half of Europe's energy needs. This projection declined until just recently. The fuel mix for West Germany shown in Figure 1 is representative of all the countries visited. Since most of the European countries are almost totally dependent on imported oil and gas, recent disruptions have caused an increase in the use of coal, wood and waste.

In 1979, wood supplied 0.2% of the total energy used by West Germany. Some forecasts call for this to increase to 2% by 1990. At any rate, the contribution from wood will probably always be quite small as only the southern states have significant (35%) forest coverage. This forest is already intensely managed. Industrial use of waste wood trees, however, appears to be on the rise.

Switzerland has shown more dependence on wood with 11% of their energy being provided by wood in 1950, and 1.5% currently. In the past few years the downward trend has reversed. The main users are rural homes and farms, and small wood working industries. Since most of the forests are owned by cities and communities, much of it is used to heat public buildings. The Swiss army heats some of its buildings with wood. There are now over 50 large installations burning wood chips. There has also been a recent increase of wood combustion in suburban homes. Tile stoves are seeing a revival and multi-fuel boilers are gaining popularity.

With its intensive farming, Denmark has no room for unmanaged forests. In rural areas farmers often maintain a firewood tree area. Though this use may be significant in certain localities, overall wood makes a negligible impact on Danish energy use. The Danes do, however, manufacture many types of wood burning equipment for both residential and industrial applications.

Of the countries visited, Sweden has the most agressive program to encourage the use of wood as fuel. Sweden too saw a decline of wood use until recently. Figure 2 shows that after 1990 a major contribution is expected from wood, especially from energy farms and integration of residue harvesting with logging. Government policy, which has far-reaching impact in Sweden, strongly promotes the installation of district heating systems. Already, more than 25% of the space heating needs for the country are supplied by district systems. This trend is expected to continue in Sweden's urban areas and constitutes the largest

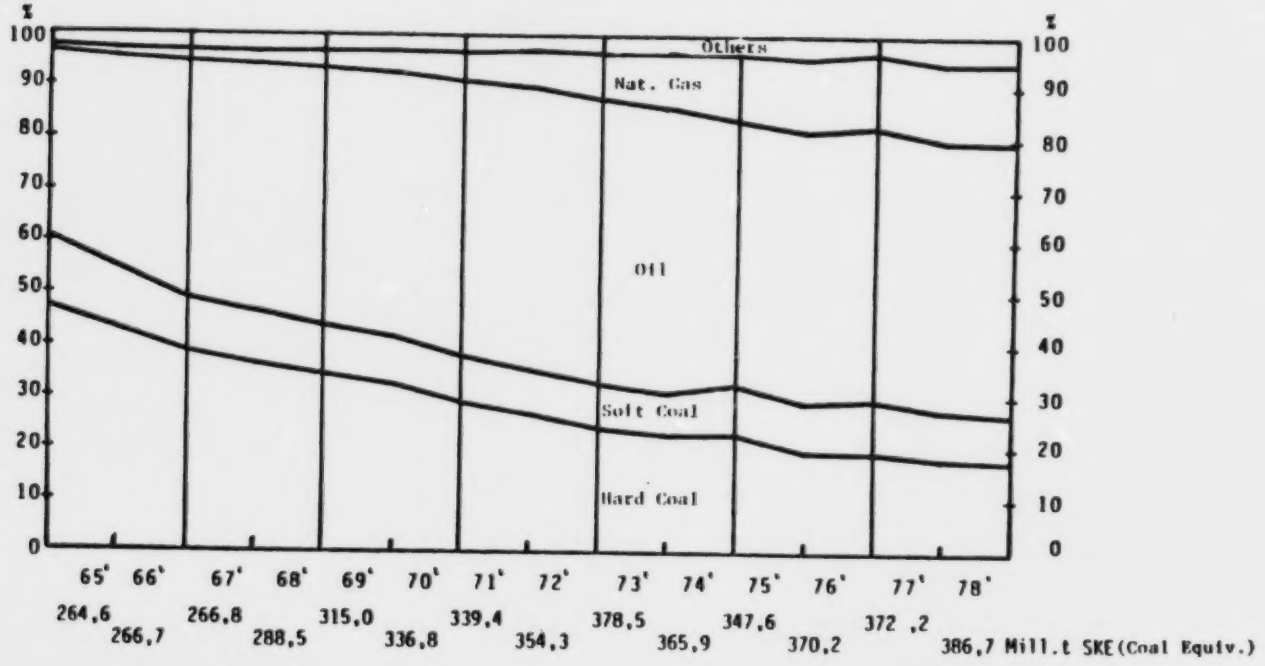

Figure 1. Primary Energy Consumption in West Germany by Energy Source, 1965-1978. (1 MM ton SKE = 25.5×10^{12} BTU) (1)

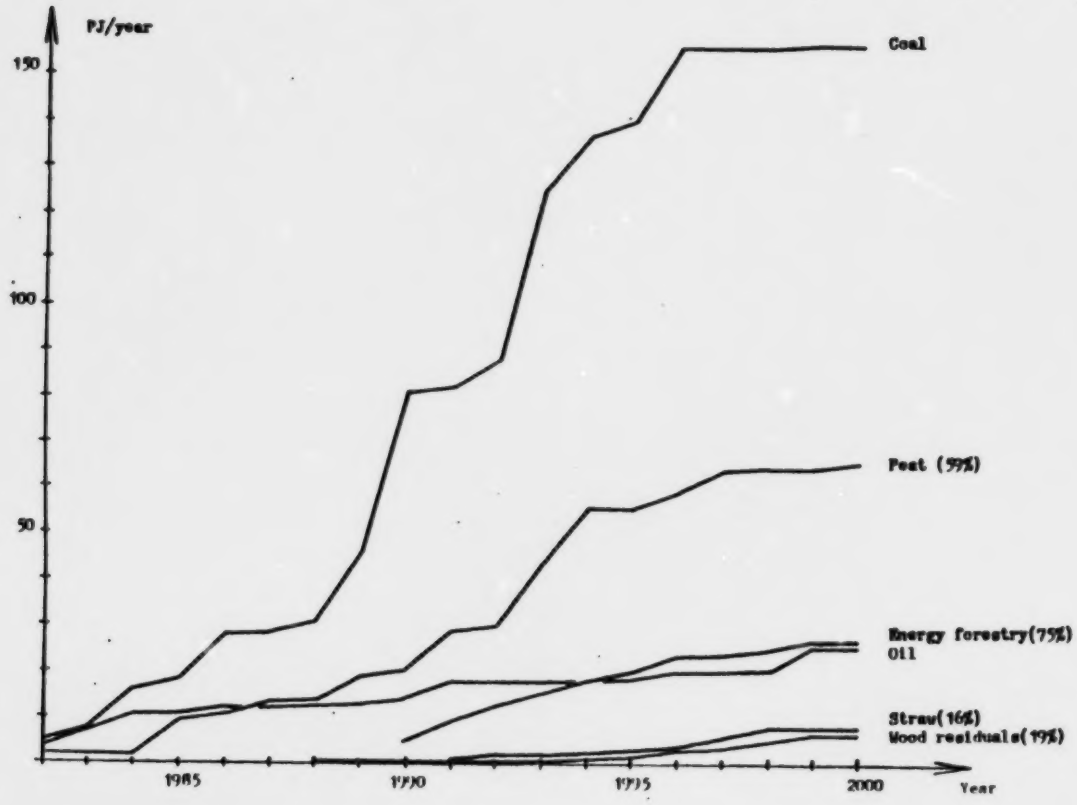

Figure 2. Forecast of Energy Use in Sweden. (2)

potential market for wood fuel.

Use of wood chips for fuel has become so significant that a law was recently passed to protect the pulp and paper industry's interests. Competition has raised the price of pulp wood which is one of Sweden's major exports. This has forced a difficult dilema for policy makers who are attempting to balance the various interests.

Finally, it is fair to say that the scarcity of wood for fuel in all the European countries has created an awareness of efficiency. Limited storage space is a further incentive for Europeans to strive hard to obtain maximum output from their fuel wood.

2.0 AIR POLLUTION CONSIDERATIONS

2.1 HISTORICAL

Most standards applicable to wood combustion derive from early European concern about particulate emissions from coal combustion. Since many types of coal were used, categorization was necessary to accomodate their different emission characteristics. Percent volatile matter became an accepted distinguishing feature. Wood then was included with other high volatile fuel such as brown coal briquets. Since smoke output is generally proportional to volatile matter content, wood and other high volatile fuels became known as "smokey fuels". Eventually regulations and equipment design reflected this distinction between "smokey" and "smokeless" fuels.

The authors reported that down-drafters produced significantly less pollution than up-drafters. This early knowledge was the basis for German regulations for small stoves, and resulted in the universal application of the "slow combustion" or Dauerbrenner stove. This type of stove is described in 3.1.3.

Since emissions from wood combustion have not been of great national concern in any of the European countries, regulations relating to wood are a part of those pertaining to particulate emissions from coal. As in the U.S., in recent years there has been increasing concern about emissions from residential appliances. Visibility problems have been documented in alpine valleys which are subject to frequent inversions. To date, however, these problems have not resulted in any regulatory action. There has also been an increasing concern about the effects of PAH emissions from wood combustion as reflected by recent conferences and health research.

In Germany combustion emissions are regulated by the Federal Air and Noise Protection Law of 1974. Switzerland is still awaiting passage of its federal environmental protection law so emissions are controlled by guidelines established by insurance companies and professional organizations (eg. engineering societies). Some local governments have passed ordinances but all enforcement is possible only through nuisance complaints.

In Sweden only large equipment (>900 MJ/h) is regulated by the federal Environmental Protection Act. The National

Environmental Protection Board can, however, recommend standards or regulations for any pollution source.

2.2 EXISTING REGULATIONS AND ENFORCEMENT

2.2.1 Residential

In Germany, residential equipment (<80 MJ/hr) is subject to two alternate requirements. Either it must be fired with a smokeless fuel or it must be an approved system type. Most models that are approved, now over 80, are the Universal Dauerbrenner type. Figure 3 gives an overview of German emission regulations for residential and small commercial heating equipment. None of the other countries have to date passed any emission regulations for residential solid fuel equipment.

Insurance companies in Switzerland require that no solid fuel fired heating appliance emit gases containing over 1% CO. The Center for Wood Combustion of the Swiss Association of Forest Owners (SVW) promotes equipment with good combustion efficiencies. An approval stamp is given to equipment which passes an efficiency test of 75%. The heat load of the grate should be within 628 and 883 MJ/m^2 h. Also, the ratio of free grate area and total grate area is regulated and should be between 25% and 30%. Finally, a federal guideline prohibits the burning of trash in fireplaces and recommends the use of dry wood. All of these guidelines and standards have indirectly affected emissions from wood combustion in Switzerland.

2.2.2 Commercial

Germany has particulate emission standards for solid fuel combustion units larger than 80 MJ/hr (75,840 BTU/hr). These standards include dust, soot and tar measured at standard conditions and a CO_2 content of 12% by volume.

- Hand-fired Units < 150 mg/m^3
- Mechanically-fed Units < 300 mg/m^3

One exemption should be mentioned. For units burning wood from wood working industries, hand-fired units must meet the 300 mg/m^3 standard. This was, at the time of the promulgation of the regulation, a concession made to the numerous small wood working shops that have a very heterogeneous wood waste available as their own energy source.

Enforcement of this German regulation is conducted as follows. The smallest category of solid fuel combustion equipment, <80 MJ (75,840 BTU/hr) is not subject to inspection unless complaints occur. For larger size ranges the chimney sweep guild is charged with the periodic inspection of the installations. Four weeks after installation of a new piece of

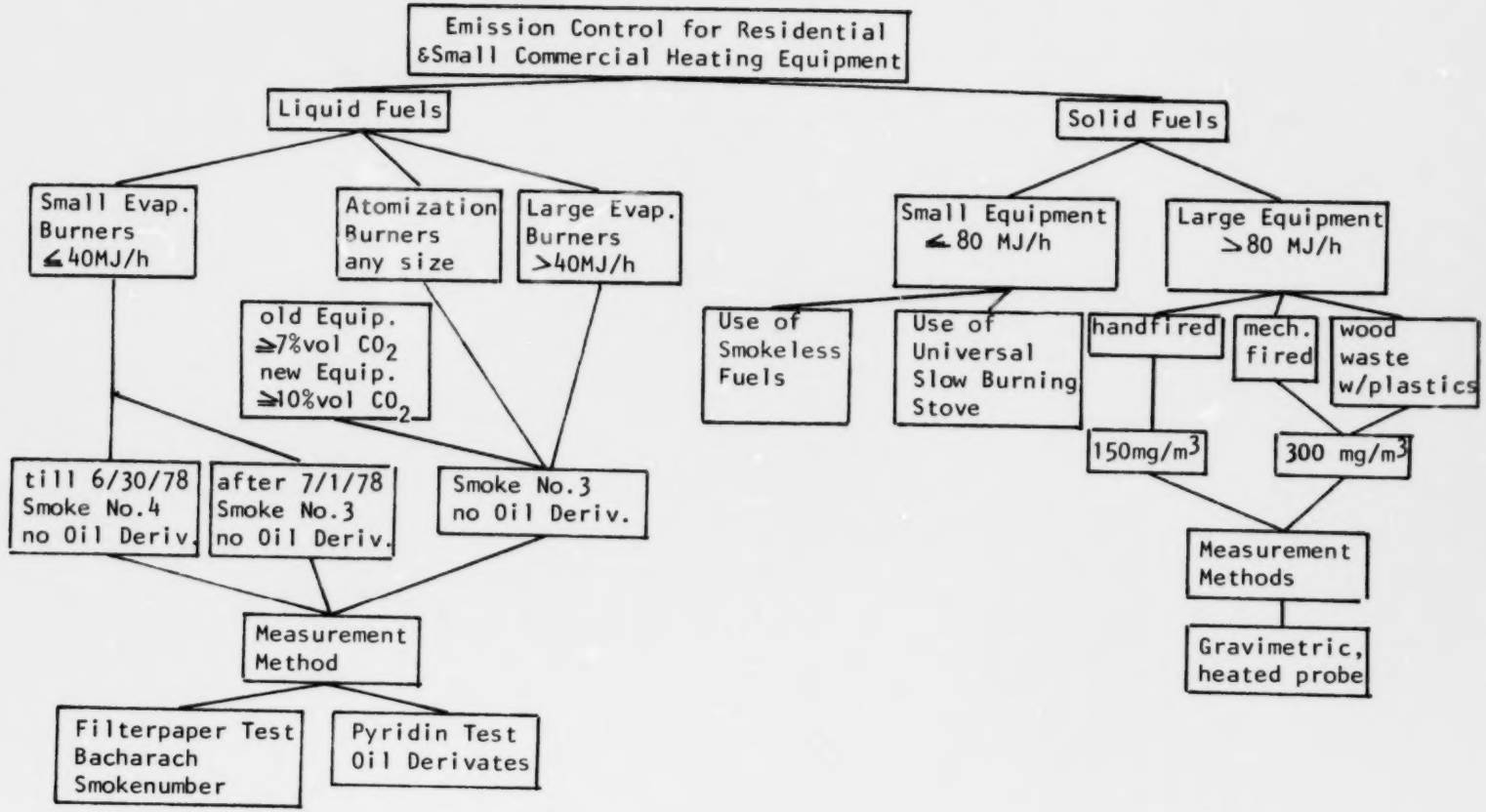

Figure 3. Overview of German Emission Regulations for Residential and Small Commercial Heating Equipment.

equipment, and once a year thereafter, the owner must have an inspection and emission measurement performed by the district sweep.

The organizational arrangements from sampling to evaluation of the filter cartridges are very elaborate as shown in Figure 4. At the district level, the actual sampling is performed by chimney sweeps with a number of certified sampling instruments. They all consist of a heated sampling probe, a filter holder, an air pump and timer. With this probe, the sampling is done with a constant velocity of 4m/sec. The total sampling volume is 90 liters.

Evaluation of the samples takes place at the Central Office of the Chimney Sweep Guild. The scale, used for weighing the dried filter cartridges, is connected to a microcomputer and printer. The tara weight is printed on the filter list. When the used cartridges come back, the same list can be put into the printer and the adjusted weight of the exposed filter is printed onto the list. In this manner the gravimetric emission result, adjusted for normal conditions and CO_2 content of 12% is obtained.

Northrhine-Westfalia has had a similar regulation for heating installations since 1970. The gravimetric emission standards for particulate matter are the same as at the federal level. However, an additional indicator is used. For small equipment, < 80 MJ/hr (75,840 BTU/hr), a second type of filter test is performed periodically. A sampling instrument similar to the common smoke test paper tape meters is used. Instead of just comparing the soot spot on the filter paper with a smoke number scale like the Bacharach scale, the filter spot is compared on a two dimensional color spot scale. That scale ranges on one axis from white to black, on the other from white over yellow to brown. Each field is labeled by a number ranging from 0 for the white to 1033 for the dark brown on the diagonally opposite side of the chart. The sampling takes place at intervals of one minute. At each sampling 0.15 liters is pulled through the filter paper. The average of all the spots should not exceed 200. These numbers reflect the gravimetric emission rate of soot and tar (3).

There is also a German guideline for the safety aspects of suspension burners. It applies only to installations above 80 MJ/hr. Most of the points covered by the guideline concern the possible back-firing through the charging mechanism into the fuel storage silo. Common ways to prevent back-firing are sluices consisting of two interlocked doors, paddle wheels, or pressure controlled doors. Suspension burners must be designed to insure that the air blower starts before the wood dust is mixed into the air stream and the blower keeps running for a while after the fuel flow has stopped. A check valve must be installed in the

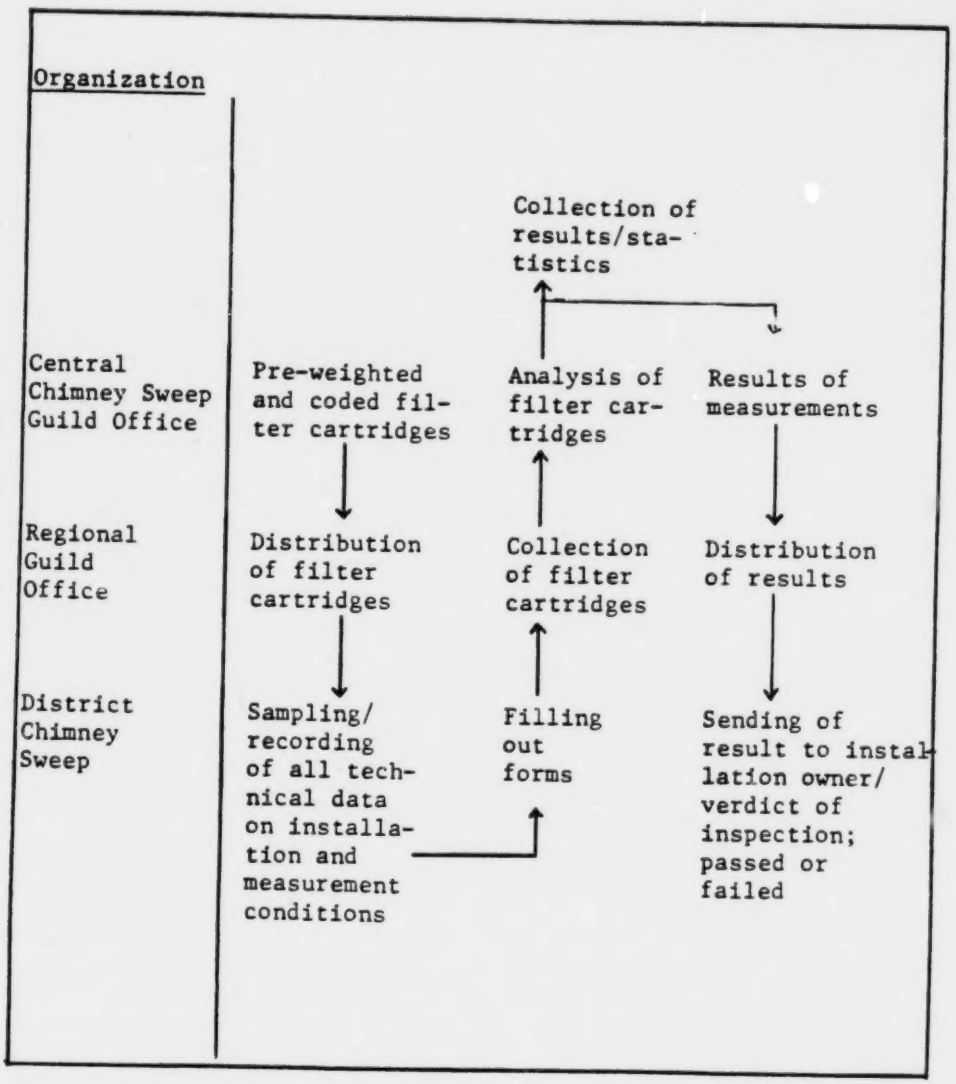
Organization
Central Chimney Sweep Guild Office
Regional Guild Office
District Chimney Sweep
Pre-weighted and coded filter cartridges
Distribution of filter cartridges
Sampling/ recording of all technical data on installation and measurement conditions
Filling out forms
Collection of filter cartridges
Analysis of filter cartridges
Collection of results/statistics
Results of measurements
Distribution of results
Sending of result to installation owner/ verdict of inspection; passed or failed

Figure 4. Organizational Arrangements for the Enforcement of Particulate Emission Standards of Solid Fuel Fired Equipment >80 MJ/hr (75,840 BTU/hr).

fuel line. Auxilliary burners are required for suspension burners. They must be connected to a flame sensor, which will turn the oil or gas burner on when the flame is lost. For steam boilers other safety requirements must also be met.

Measurements performed by the Swiss Federal Materials Testing Laboratory (EMPA) (4) in 1978 showed that most installations emitted less than 104 ug/J suspended particulate matter. This has resulted in recommendations to the Swiss Office for Environmental Protection concerning particulate matter emission standards for large central heating plants. Some requirements of an existing guideline for emissions from municiple waste incinerators might be extended to wood combustion equipment. In particular, the CO volume percentage in the stack gases shall not exceed 0.1% of the CO_2 volume percentage.

Similar to West Germany, the chimney sweeps in Switzerland inspect and maintain heating systems. All combustion equipment and chimneys must be swept and inspected once a year. For solid fuel fired equipment, however, no emission standards exist.

2.2.3 Industrial

Germany has particulate emission standards for solid fuel installations larger than 1 MW. Wet wall boilers must meet 300 mg/m^3 or 165 ug/J and water tube boilers 150 mg/m^3 or 79 ug/J. Emission measurements must be taken during operation at design load and are adjusted for 13% volume of oxygen content. The standards must be met even during soot blowing. Carbon monoxide (CO) is also regulated. A concentration of 250 mg/m^3 may not be exceeded.

A draft of proposed emission standards for solid fuel boilers (VDI Guideline 2300 (9)) contains many design factors, such as maximum grate loads or firebox wall loads. The emission standards and some of the more important parameters are listed in Table 1.

Sweden regulates solid fuel combustion equipment in the capacity range of 900 to 36,000 MJ/hr. In industries the regulations apply only to combustion for process heat. The National Environmental Protection Board, as a central administrative authority can, however, recommend standards and other measures for any pollution source. The Board presently suggests a particulate standard of 165 ug/J or 300 mg/m^3. Most of the conventional equipment in this capacity range has a forced air draft system and therefore needs cyclones to meet the standard.

For installations above 10 MW, the Board has control of emission requirements and is working on a particulate matter standard. The ideal level for the standard would be 55 ug/J or 100 mg/m^3. This standard calls for an electrostatic precipitator or a baghouse for most equipment.

Table 1. Proposed VDI Emission Standards for Boilers and Typical Wood Boiler Parameters (Equipment up to 100 metric tons per hour). (Appendix E)

Emissions [1]	INCLINED GRATE & SUSPENS.	FLAT GRATE & SUSPENS.	FLAT GRATE PRECOMB.	TRAVEL. GRATE
Particulate matter in mg/m^3 [2], raw gas	300-800	600-2200	1000	500-800
Particulate matter standard in mg/m^3 [2]	300			
Nitrogen oxides standard in mg/m^3	1300			
Carbon monoxide standard in mg/m^3	500			

Typical Parameters	LOGS & PIECE WOOD	SHAVING & WOOD CHIPS	SAW-& SANDER DUST
Ash content %wt	0.3-1.5	0.3-1.1	0.2-1.0
Water content %wt	5.0-50	5.0-50	5.0-15
Volatile matter %wt			
Heating value kJ/kg	7,500-17,000	9,000-17,500	15,500-17,500
Grate load kg/m^2-h	250-500	300-550	-
Firebox load kJ/m^3-h	840-1,680,000	840,000-2,100,000	420-1,260,000
Stack gas temp. °C	200-300	200-300	200-300
CO_2 content %vol	8-11	8-11	8-11
Stack gas volume in m^3/kg wood	5.5-12.5	6.0-13.0	8.0-13.0

1) all conc. at 273°, 1013×10^5 Pa , moisture-free, 13% O_2
2) at least four measurements, each less than two hours at constant design load, soot blowing, if any, included

100 mg/m^3. This standard calls for an electrostatic precipitator or a baghouse for most equipment.

2.3 REPORTED EMISSIONS

Most of the emission data found in Europe is produced by government agencies who are responsible for testing and certifying equipment. Most of this is done using VDI (Association of German Engineers) standards. References may be found in Appendix E. Manufacturers are required to test their own equipment and verify that it meets the regulations.

Table 2 summarizes available emission data. It is organized to correspond to the order presented in Chapter 3.

2.3.1 Residential and Commercial

Two fireplaces were tested by Rudling et. al.(5). Braskamin I is a fireplace without a warm air heat exchanger, but with a glass door and outdoor combustion air. Braskamin II had a built-in warm air heat exchanger. Pollutant concentrations in the stack gases of the two fireplaces were very similar. The higher thermal efficiency of the Braskamin II, however, resulted in lower emission rates per unit of heat output (ug/J out). Emission rates from Braskamin II were about 1/2 those from I. Note that in both cases the reported efficiency is much higher than commonly reported in the U.S. literature.

All of the residential boilers described in this report must meet the West German TSP standard. Capacities and efficiencies are based on information from the manufacturers. Therefore no specific data is available; all that is known is that the standard is met.

A detailed emission analysis of two types of residential boilers was also performed by Rudling et. al. Emissions from a pre-chamber boiler were compared with those from a standard grate fired boiler. Both of them were fired with wood chips, controlling for firing rate, moisture content, and excess air. Tables 3 and 4 contain the significant data from that study.

In the standard grate type residential boiler the only factor having an influence on TSP & POM is the excess air level. The highest CO_2 value is accompanied by extremely high PAH values. The moisture content of the wood and the firing rate appeared to have little influence on the pollutant concentrations.

The pre-chamber system is composed of the standard grate fired boiler used in the first system, but with a gravity fed pre-chamber as described in 3.1.6. It is difficult to draw conclusions from the data presented in Table 3, since too many

Table 2. Summary of Emission Data of Wood-Fired Equipment in Europe. (Manufacturers see Appendix D)

Equipment Type	Output Capacity MJ/h	Efficiency %	Manufacturers	Average Emissions (µg/ J)			Remarks
				TSP	POMs	Others µg/J	
Residential							
Fireplaces							
Braskamin I	21.5	40-45		5.7-170	0.3-17	CO:0.6-7.3	(5)
Braskamin II	43.0	70-80		16-78	0.3-7	CO:1.1-0.8	(5)
Tile Stoves	2.5-6.3	75-85					Capacity in MJ/m^2h (6)
Boilers							
Multifuel(1 Firebox)	61-600	65-85	1,2	≤79*			lower efficiency for oil
Multifuel(2 Fireboxes)	61-600	70-85	1,2	≤79*			
Solid Fuel	60-1420	70-85	1,2	≤79*			
Solid Fuel w/DHW tank	60-146	50-85	1	≤79*			lower efficiency summer
Pre-Chamber (for Logs)	125-2000	70-85	3	≤79*			
Pre-Chamber (for Chips)	125	80-85	14	45-1600	0.004-8.3	CO:0.06-5	(5)
Commercial							
Boilers							
Handfired/Susp.Comb.	$277-2\cdot10^3$	70-80	4,5,6	≤156*			
Pre-Chamber, Handfired	$250-3\cdot10^3$	75-85	15	≤ 79*			
Moving Grate (Chips)	$1.4-6\cdot10^3$	75-85	6	≤156*			
Industrial							
Boilers							
Retort, Stoker	$3-5\cdot10^3$	75-84	7,8	194			w/ multi-cyclones (4)
Cyclone Burner	$1-50\cdot10^3$	84-88	9,10	26-77	0.001		w/ elec. precip. (7)
Fluidized Bed	$1-50\cdot10^3$		16	2.0			w/ baghouse (10)
Inclined Moving Grate	$16\cdot10^3$		6,11	28			fired w/wet bark(8)
Handfired/Susp. Comb.			6	77-155			(4)
Dutch Oven Type	$2.6-16.2\cdot10^3$		6	103-252			(4)
Gasifiers	$3\cdot10^3$		11,12 13			CO:1.26 Ald.:0.76	pollutants measured in exhaust gas of IC-engine (9)

* Standard of West Germany.

Table 3. Emissions from a Standard Grate Fired Wood Chip Boiler

Parameter	Units	Test 1	Test 2	Test 3
Firing Rate	kg/h	7.0	7.0	13.0
Moisture Content of Wood	%	14	14	36
Stack Gas Temperature	°C	200	200	190
CO_2	%	8.0	5.7	5.0
CO	ppm	8,000	6,000	6,500
H_xC_y	ppm	NA	NA	NA
TSP	mg/m^3 (at 10% CO_2)	360	120	260
PAH	$\mu g/m^3$ (at 10% CO_2)	16,000	25,000	2,800

Table 4. Emissions from a Pre-Chamber Wood Chip Boiler

Parameter	Units	Test 1	Test 2	Test 3	Test 4
Firing Rate	kg/h	4.2	7.0	7.0	7.0
Moisture Content of Wood	%	21	48	48	48
Stack Gas Temperature	°C	150	190	190	180
CO_2	%	6.5	6.7	7.0	4.0
CO	ppm	60	700	2,100	2,500
H_xC_y	ppm	30	50	110	400
TSP	mg/m^3 (at 10% CO_2)	72	72	80	2,300
PAH	$\mu g/m^3$ (at 10% CO_2)	<6.8	42	220	2,300

variables changed from one test to the next. Again, the excess air level, as indicated by the CO_2 concentration seems to be the most important variable associated with the changes in TSP and PAH concentrations. In test 4 the excess air seems to be too high to maintain adequate combustion temperatures at the given firing rate. Rudling et. al. concluded that increased firing rates will produce higher TSP and POM emissions and that higher moisture content results in higher PAH emissions.

It is difficult to compare emissions from the two system types since moisture content and firing rates were not well controlled. At design capacity (7kg/h) TSP concentrations in the pre-chamber system were reported to be lower by a factor of 1.5 to 5. PAH concentrations were also reported to be much lower in the pre-chamber configuration.

2.3.2 Industrial

There is a wide variety of industrial combustion equipment. Retort under fed stokers are very common in the lower capacity ranges. They reach efficiencies up to 85% and can handle dry and green chips. TSP emission are not excellent because the forced combustion air carries all the ash through the boiler. Manufacturers claim, however, that the particulate matter passing through the multi-cyclone is exclusively light fly ash.

Tests of a Swedish cyclone burner revealed very low TSP and POM emissions (7). The burner is part of a district heating system in southern Sweden (Vaxjo) and burns a mixture of wet bark and green chips. The cyclone burner exhausts to a normal oil-fired boiler (see 3.3.2). The system is equipped with an electrostatic precipitator.

A fluidized bed plant of the type described in 3.4.3, has been tested in Eksjo, Sweden (10). The plant is equipped with a baghouse and fires wet bark and green chips and, for a few hours every day, municiple solid waste. This multi-fuel approach with fluidized bed combustors has created great interest in Sweden. The Swedish National Board of Environmental Protection conducted an emission test on that particular unit and found average TSP concentrations as low as 5 mg/m^3 , or approximately 2 ug/J.

Inclined moving grate boilers are often found in pulp and paper mills where wet bark and even waste water treatment plant sludge is burned (see 3.3.4). One particular boiler of this type has been tested for particulate matter (8). Average TSP emission was found to be only 28 ug/J using simple mechanical filters.

The Swiss Federal Materials Testing and Research Institute (4) has done an emission field survey among typical wood fired industrial boilers in Switzerland. Dutch-oven, suspension burner and stoker retort type boilers were the most prevalent. The

investigators suggested that a nation-wide TSP emission standard of about 85 ug/J could be justified since more than half of the tested installations meet such emission levels. In some cases 85 ug/J can be reached using only a settling chamber.

2.3.3 Swedish PAH Emission Study on Wood Heaters

Only in Sweden has research been done specifically on POM's from wood combustion. Rudling et. al. (5) sampled wood emissions and performed bio-assays (mutagenicity tests) on them. The sampling train and method of analysis are depicted in Figure 5. Gas chromatography has been used to identify individual PAHs. A standard Ames-Test with salmonella/mammalic-microsomes was performed using extracts from the particulates, the condensates and the absorbent. Emissions tests were performed on several types of equipment over a range of combustion conditions. The authors concluded:

1. It was very difficult to adequately control all the variables.
2. Equipment design differences effect the extremes of PAH emissions and mutagenicity; the high and low ends seem to be affected the most.
3. Firing rates, fuel/air ratios, and fuel moisture content settings do influence emissions and mutagenicity.
4. PAH emission and mutagenicity increased as firing rate increased in the pre-chamber Villapanna boiler.
5. Emissions and mutagenicity in the log fired boiler show a decrease with higher firing rates.
6. Up-drafters show less harmful emissions when fired beyond capacity than cross/down-drafters.
7. Cross/down-drafters show lowest critical emissions at half capacity settings.
8. High moisture content seems to have more effect on PAH emissions and their characteristics in fireplaces than in boilers.

Among the PAH detected in emission samples of wood stove exhaust gases are Phenanthrene, Anthracene, Fluoranthene and Pyrene. Not all of these PAHs are proven to be carcinogens. Among the proven carcinogens, Chrysenes, Benza(a)pyrene, and Benzo(a)anthracene had the highest concentrations. It is also interesting to see from the data presented by Rudling that the relative concentration of individual PAH does not change with equipment design variations and combustion conditions.

Tomingas (18) summarized carcinogenicity of PAH occurring in atmospheric particulate matter (see Table 5).

2.4 TRENDS IN EUROPEAN POLICIES

In general, the European strategy governing emission regulations for wood combustion equipment has placed its emphasis on enforcement; this has resulted in simple, fairly uniform and not very stringent standards. These are generally

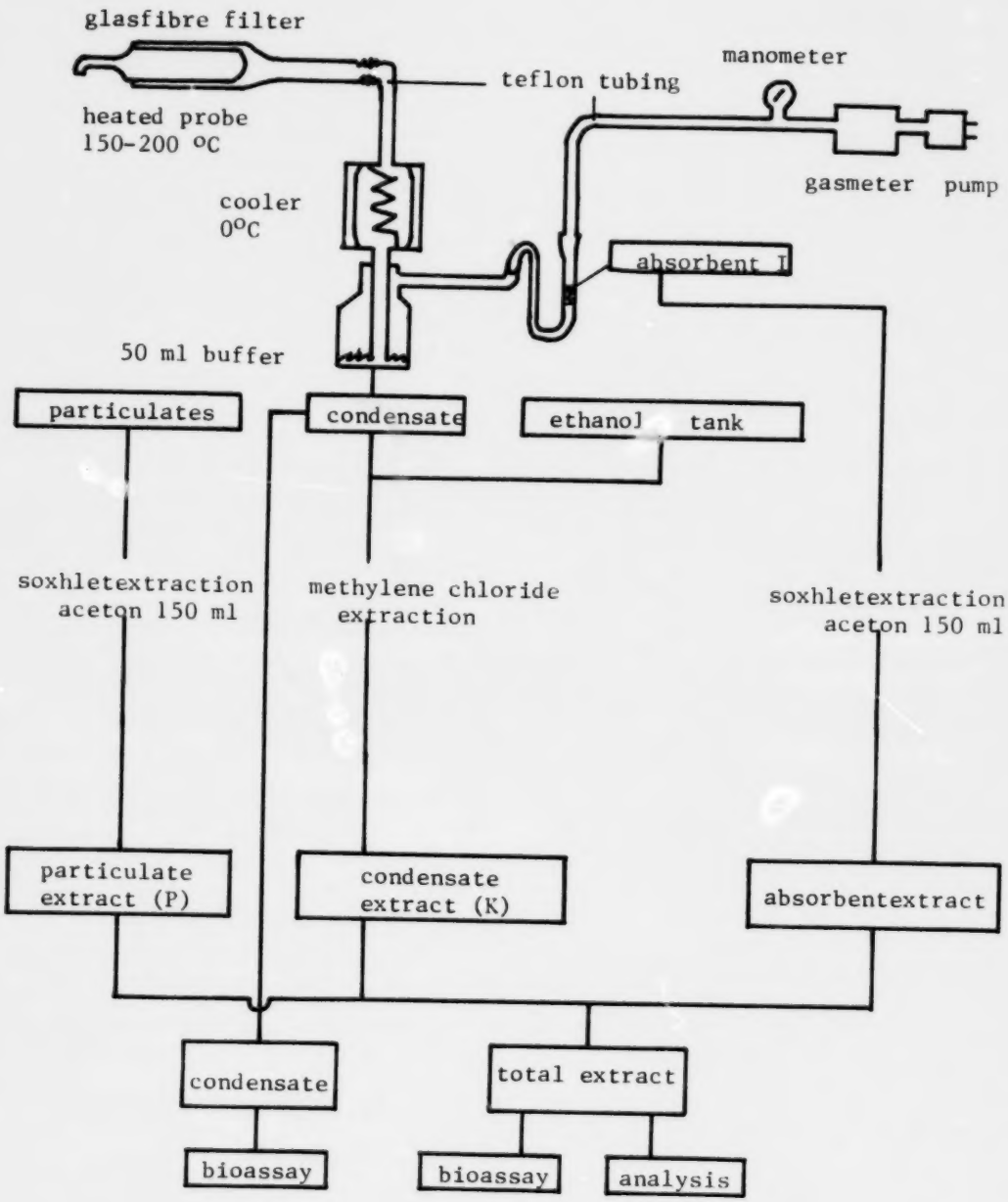

Figure 5. Flue Gas Sampling, Extraction, and Analysis Used in Swedish Wood Heater Study. (5)

Table 5. Carcinogenicity in Epicutaneous Tests of PAH Occurring in Air Particulate Matter. (18) (Reproduced with Permission)

Substance	Carcinogenicity	Author(s) (32)
Anthanthrene	+	Cavalieri et. A., 1977
	-	Hoffmann and Wynder, 1966
	-	Lijinski and Garcia, 1972
Benzo(a)pyrene and metabolites	+	Cavalieri et al., 1977
	+	Hoffmann and Wynder, 1966
	+	Lee and O'Neill, 1971
	+	Levin et al., 1976, 1977
	+	Schmidt et al., 1973
	+	Wynder et al., 1957
Dibenz(a,h)anthracene	+	Hoffmann and Wynder, 1966
	+	Johnson, 1968
Dibenzo(a,e)pyrene	+	Hoffmann and Wynder, 1966
Dibenzo(a,i)pyrene	+	Hoffmann and Wynder, 1966
Dibenzo(a,h)pyrene	+	Cavalieri et al., 1977
	+	Hoffmann and Wynder, 1966
Dibenzo(a,l)pyrene	+	Hoffmann and Wynder, 1966
Benzo(b)fluoranthene	+	Wynder and Hoffmann, 1959
	+	Habs and Schmähl, 1978
	-	Mohr, 1969
Benzo(j)fluoranthene	+	Wynder and Hoffmann, 1959
	+	Habs and Schmähl, 1978
	-	Mohr, 1969
Benzo(k)fluoranthene	-	Habs and Schmähl, 1978
	-	Mohr, 1969
	-	Wynder and Hoffmann, 1959
Benzo(a)anthracene	+	Kinoshita and Gelboin, 1972
	+	Scribner, 1973
	+	Slaga et al., 1974
Chrysene	+	Hecht et al., 1974
	+	Hoffmann et al., 1974
	+	Scribner, 1973
	+	Van Duuren et al., 1966
Cyclopentadieno(c,d)-pyrene	-	Brune, 1978
	-	Habs and Schmähl, 1978
Anthracene	(+)	Scribner, 1973
	-	Maisin et al., 1927
	-	Barry et al., 1935
Phenanthrene	(+)	Roe, 1962
	(+)	Scribner, 1973
	-	Roe and Grant, 1964
Fluoranthene	-	Hoffmann et al., 1972
	-	Horten and Christian, 1974
Benzo(e)pyrene	-	Goldsmith et al., 1973
	(+)	Scribner , 1973
Pyrene	-	Goldsmith et al., 1973
	(+)	Horten and Christian, 1974
	-	Roe and Grant, 1964
Perylene	-	Horten and Christian, 1974
	-	Van Duuren et al., 1970
Indeno(1,2,3-cd)pyrene	+	Hoffmann and Wynder, 1966
	-	Habs and Schmähl, 1978
Coronene	-	Habs and Schmähl, 1978
Fluorene	-	Arcos and Argus, 1968
Benzo(ghi)fluoranthene	-	Wynder and Hoffmann, 1959
Triphenylene	(+)	Horten and Christian, 1974
Indeno(1,2,3-cd)-fluoranthene	+	Hoffmann and Wynder, 1966
Benzo(ghi)perylene	-	Müller, 1968
Benzo(a)fluorene	-	Arcos and Argus, 1968
Benzo(c)fluorene	-	Arcos and Argus, 1968
7,12-Dimethylbenz(a)-anthracene	+	Roe, 1956
	+	Slaga et al., 1974

+ = Carcinogenicity proven
(+) = Indication of possible carcinogenicity
- = Carcinogenicity not proven

regarded as sufficient especially considering the relative scarcity of wood for fuel. Thus, most officials interviewed did not foresee any major air pollution problems related to wood combustion, though localized problems are anticipated.

There is however a trend in Switzerland and West Germany to set efficiency standards for heating equipment. Equipment efficiency is linked to total emissions and therefore those standards, e.g., in West Germany, are promulgated under the federal environmental laws. The efficiency of equipment has been defined by the ratio of total input energy (as 100%) minus the energy loss through the stack gases. There are some other standards defining the maximum idle loss of boilers. This includes the radiation and convection losses of the boilers. As noted earlier, manufacturers actively oppose these standards making their future less certain.

The inspection and maintenance programs required for certification are viewed very favorably by European officials. Although the program began for pollution and nuisance control, it has been expanded to include simple efficiency testing. This annual or biannual program has resulted in a very high awareness and understanding of how to maximize efficiency in the operation of small wood burning appliances.

Sweden is encouraging the use of wood as a fuel when it can be burned very efficiently. Thus, although district heating systems are only marginally attractive economically, many are being installed. These installations are both efficient and clean.

Officials did express some concern about possible emission problems from cofiring of wood and coal. This practice is expected to increase. At present, there are no small appliances which can efficiently burn coal and wood simultaneously. As mentioned previously, this desire on the part of the consumer for fuel versatility runs counter to the imposition of emission standards.

The specific issue of polycyclic organic matter (POMs) has been addressed in Sweden, West Germany, and Switzerland. In 1979 the West German Environmental Protection Agency discussed an air quality standard for benzo(a)pyrenes in ambient air. A 10 nanogram per cubic meter standard was considered. The result of a large conference in 1979 was that from an epidemiological point of view, no minimum dose exists at which the health risk would be acceptable. The attempt to set that standard was dropped and has not been attempted again.

The Swedish National Board of Environmental Protection has calculated that a certain density of residential homes using wood heating equipment should not be exceeded in order to avoid ambient POM concentrations which would cause an excessive health risk. Although the health implications of wood combustion pollutants have not been determined in the various Swedish research efforts, it was determined that in order to avoid ambient concentrations typical for urban areas, the flue gases from wood stoves need to be diluted 50 to 50,000 times. Medium distance requirements between individual houses, assuming a certain source, have been promulgated by local governments as a means of controlling the problem.

3.0 COMBUSTION TECHNOLOGIES

The combustion equipment presented in this chapter has been divided into three categories; Residential Space Heating, Commercial Applications, and Industrial Applications. The equipment described represents a good cross-section of the technologies available on the European market. For each piece of equipment a brief explanation about its specific use and a description of the equipment is followed by a listing of the special features and their influence on efficiency, emissions and convenience.

3.1 RESIDENTIAL EQUIPMENT

Unlike in the U.S., free standing metal wood stoves are not extremely popular. Instead, wood is usually burned in one of four types of appliances; a masonry/tile stove, a combination cookstove and boiler, a multi-fuel boiler, and in some cases, fairly efficient fireplaces.

Since most of the forest is owned by local government, wood is normally gathered and prepared by the user rather than by commercial wood dealers. Towns will issue permits to cut certain trees which have been marked by the town forester. This results in professionally managed forests which produce far greater yields than most privately owned forests in the U.S. In Switzerland there is a law which requires the planting of new trees on a one for one basis even on private land. A permit is required to clear cut anywhere. This concern for preservation is also manifest in the wood burning equipment commonly found in Europe.

3.1.1 Fireplaces

In Europe, fireplaces are normally considered luxury items, installed only for their aesthetic value. In the past few years however, "warm air" fireplaces have become popular. These are erected on-site by the fireplace mason, the Hafner, often using pre-fabricated components. Metal fireplace inserts are virtually unknown.

Concept

The typical fireplace has glass doors. Outdoor combustion air is introduced under the grate (2). Combustion takes place in a firebrick lined firebox (5). The gases then pass a heat exchanger (1) and are exhausted out the masonry chimney. Room air is drawn through a filter by a fan (4), forced through the heat exchanger, then exhausted to the room.

Applications

Fireplaces are used in single family housing, usually to supplement oil or gas or to be used in an emergency.

Comments

The firebrick lining allows a very hot fire, reducing emisisons. Further efficiency is gained by the controlled introduction of outside air for combustion. The removeable ashbox allows convenient ash disposal.

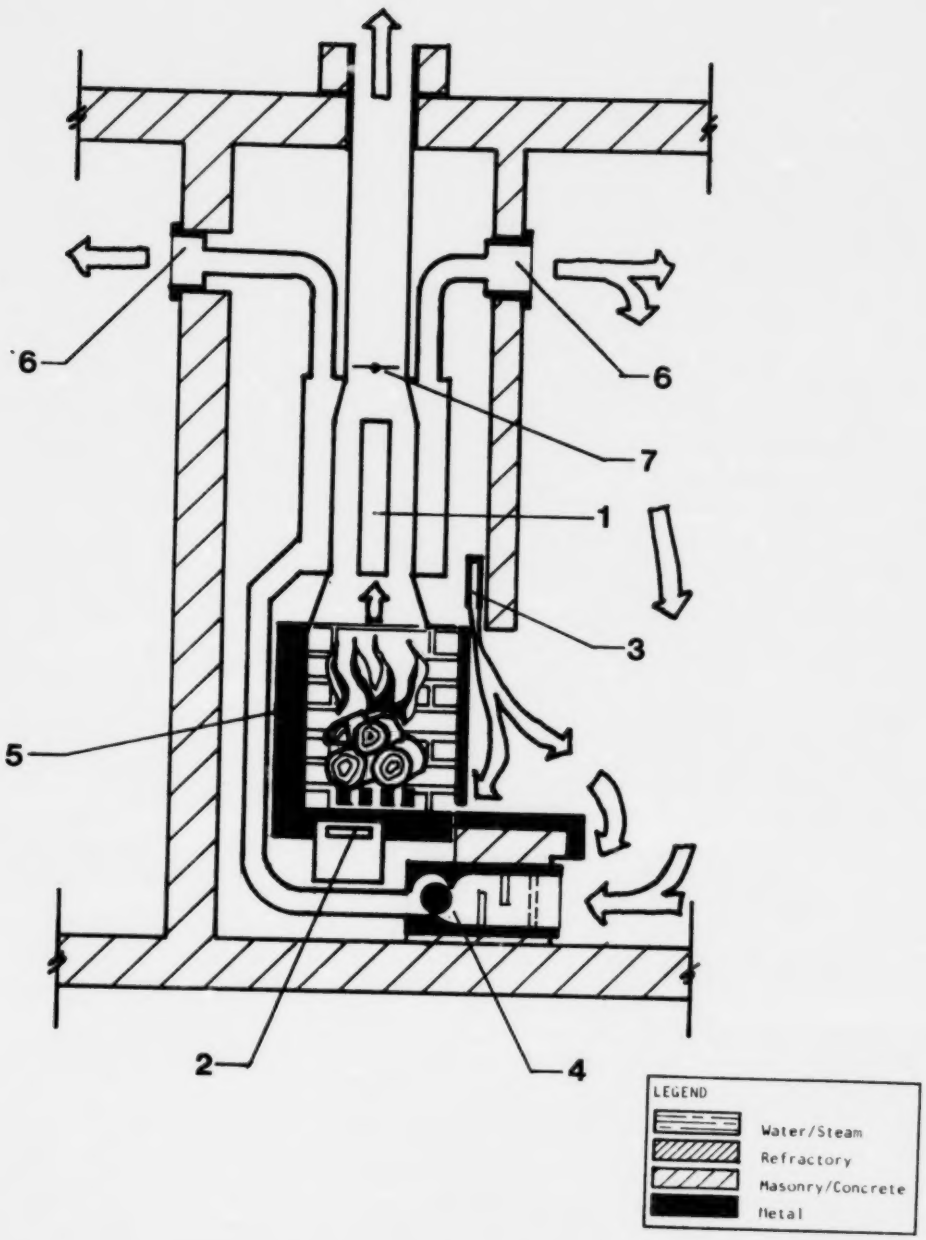

Figure 6. Warm Air Fireplace: 1 heat exchanger; 2 ash box with fresh air inlet; 3 fresh air inlet; 4 fan assembly with noise baffles and filter; 5 firebrick lined firebox; 6 warm air discharge; 7 draft damper.

3.1.2 Tile Stoves

Concept

The tile stove (Kachelofen) has a firebox (1) surrounded completely by a large mass of masonry. The combustion gases leaving the firebox meander through firebrick flues (4) giving off the heat to the masonry mass (6). This heat moves through the tiles to the exposed surface of the stove and is given off to the living space in the form of radiant and convective heat. Many modern tile stoves also have a water tube jacket (2) lining the firebox. The hot water is either used for domestic hot water or for heating in other rooms. The tile stove is most efficient when located in the center of the living space.

Applications

Traditionally tile stoves were built in farm houses. They are not well suited to retrofitting; new, single family residences, where the stove can be designed and built into the spacial arrangements, are the best applications. The average capacity ranges from 2.5 to 6.3 MJ/m^2 of exposed tile surface and per hour. The weight ranges from 50 to 100 kg/kJ output.

Manufacturers

Normally these stoves are custom built by Hafners (firebrick masons), but there are a few manufacturers of pre-fabricated elements.

Comments

The revived enthusiasm for tile stoves in Europe came with the large increases in oil prices in the mid 1970's. The tile stove concept offers two major advantages over metal stoves. First, it stores heat for 4 to 8 hours depending largely on the weight of the mass involved. Secondly, it allows operation with only a few firings per day, making it very convenient.

Thermal efficiency and air pollutant emissions are very favorable. Wood can be burned at high firing rates, at the ideal air setting and therefore hot and complete combustion can occur.

The flue system in the masonry body of the stove can be cleaned through round openings especially built in for that purpose. Virtually no engineering data and design criteria are available. The designs were passed on within guilds from generation to generation.

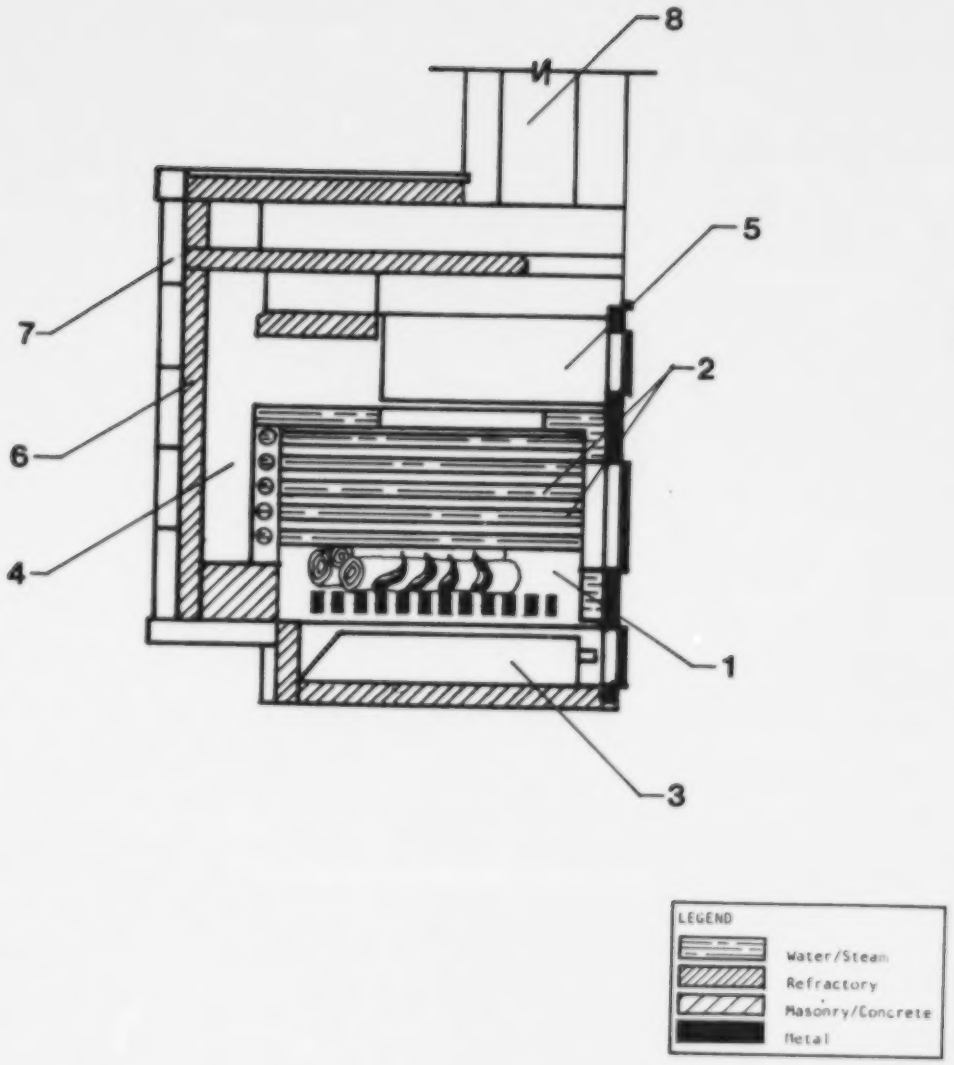

Figure 7. Tile Stove with Water Jacket: 1 firebox; 2 water pipes connected to central heating or domestic hot water; 3 ash drawer; 4 flues, firebrick; 5 oven, optional; 6 outside firebrick or fireproof concrete mantel; 7 tiles.

3.1.3 Universal Dauerbrenner (Slow Burning Down-Drafter)

Concept

This down-drafter consists of a cast iron grate (1), which is located at the bottom of the fuel magazine (4). Wood is charged through the top door (2). The vertical walls of the stove consist of two shells. The inner shell (3) forms the fuel magazine. The outer shell (5) forms a cavity with the inner shell (6). The combustion gases move through this cavity from the grate upwards to the flue connector (7) in the back of the stove. Vertical openings (8) in the conical shaped bottom of the fuel magazine allow combustion gases to leave the grate area sideways into the stove wall cavity (6). Combustion air enters through an opening (9) in the side of the stove. A damper (10) controlled by a bi-metalic thermostat (11) allows the proper amount of air to enter directly under the grate and to rise through an additional cavity (12) to the top of the fuel magazine. The air moving through the cavity (12) is preheated by the outer shell (5) of the stove and is pulled down through the fuel magazine toward the grate by the natural draft of the stove and chimney. The downward drafted combustion air picks up all of the smoldering gases given off by the wood in the fuel magazine. This mixture of air and wood gases burns together with the charred wood reaching the grate. The ashes drop through the grate into an ash drawer (13). Several sheets of metal (14) act as heat shields. This whole assembly is surrounded by an enamel surfaced metal casing (15).

Applications

This system is used as a room heater in residential and small commercial buildings; mostly designed for coke and hard coal.

Manufacturers

There are over 80 approved stoves from more than 20 manufacturers in West Germany, e.g. Buderus.

Comments

As explained in Chapter 2, this design is required by German regulations for the use of smokey fuels. Down-drafters have shown their superiority in tests (21) in particulate matter emissions, efficiency and convenience.

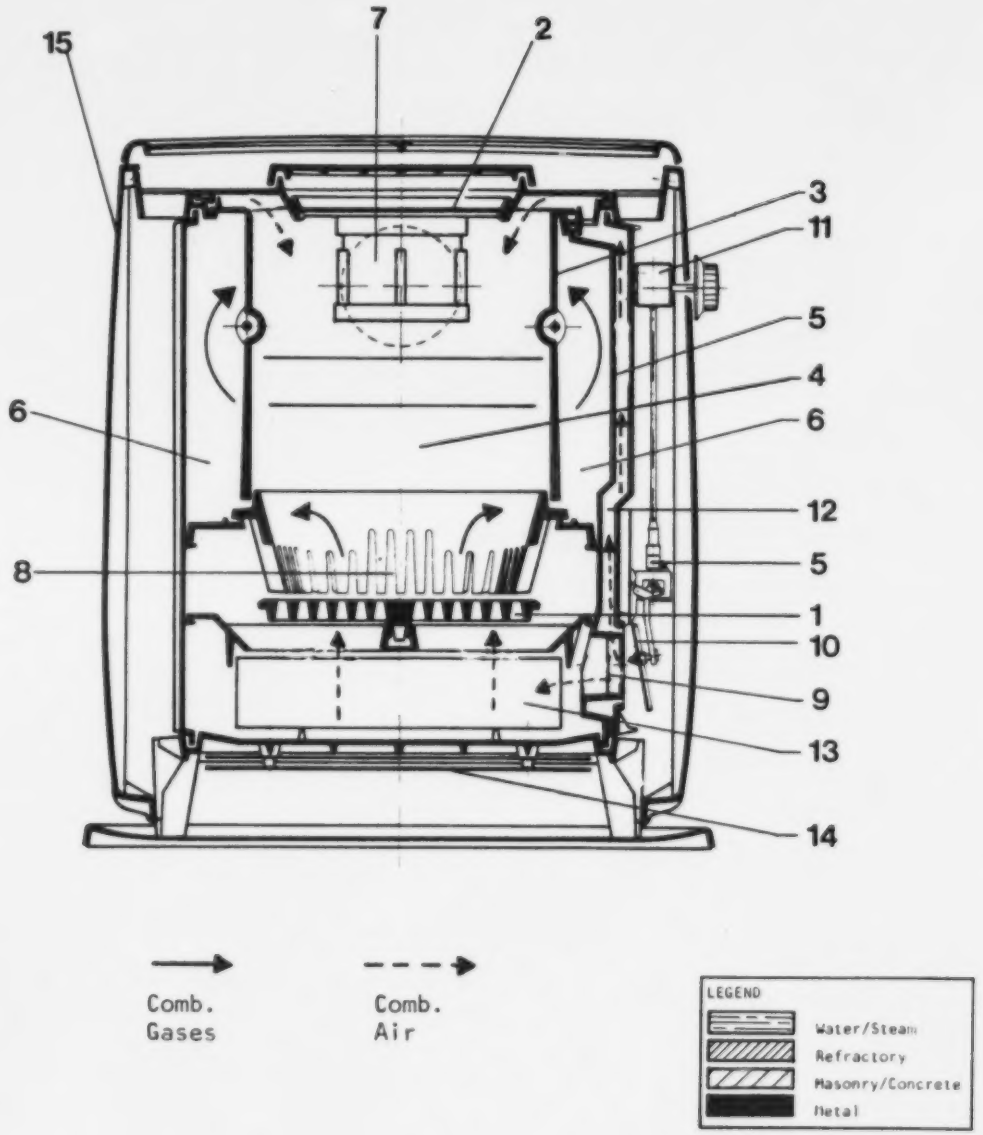

Figure 8. "Universal Dauerbrenner", Slow Burning, Down-Drafter: 1 cast iron grate; 2 charging door; 3 inner shell; 4 fuel magazine; 5 outer shell; 6 cavity with combustion gases; 7 flue connector; 8 vertical openings; 9 combustion air inlet; 10 air damper; 11 bi-metalic thermostat; 12 combustion air preheat; 13 ash drawer; 14 heat shield; 15 enamel surfaced casing.

3.1.4 Central Heating Boilers

Among the most popular central heating systems are the dual or multi-fuel hot water boilers. Generally, three types can be distinguished:

- boilers with one combustion chamber and simultaneous dual fuel capacity
- boilers with one combustion chamber
- boilers with two separate combustion chambers, one for each fuel

Most of the boilers have cross- or down-draft concepts for the solid fuels part. They are all well insulated and therefore have very small radiation losses. Practically all solid fuel fired boilers have non-electric thermostats controlling the combustion air damper. The boiler water therefore can be kept within fairly close temperature limits. For start-up, a by-pass damper can be used to overcome initially poor draft conditions.

3.1.4.1 Dual Fuel Boilers With One Firebox

Concept

This dual fuel boiler consists of one combustion chamber. The wood is charged through the upper door which also supports the oil or gas burner (4). The wood will burn as it reaches the grate (1) and is exposed to the combustion air flowing across the grate from the air damper (2) to the opening in the first water wall baffle. A by-pass damper (5) allows easy start-up. Below the grate, an ash drawer box (7) allows easy ash removal. Combustion gases make two vertical passes in the back of the firebox and leave the boiler through the flue pipe connector (8). A clean-out access door allows removal of soot deposited on the vertical heat exchanger walls.

Applications

These boilers are used in single family dwellings, 61 to 600 MJ/hr, mainly where oil or gas is only used as back-up.

Manufacturers

Hoval, CTC

Comments

This type of boiler is not in great demand any longer. Adverse publicity about the relative low efficiency of oil and gas burners on this type of dual fuel boiler has shifted the interest to boilers with two separate fireboxes.

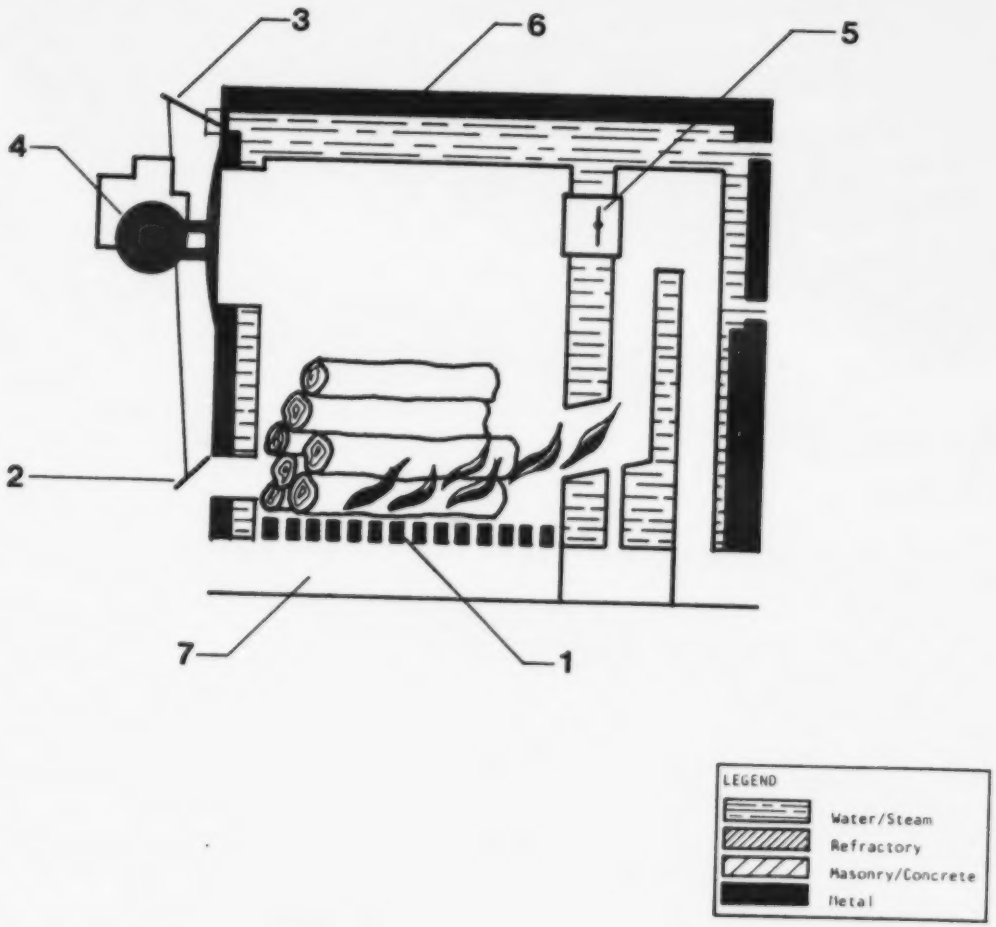

Figure 9. Multi-Fuel Boiler, One Combustion Chamber: 1 cast iron grate; 2 thermostatically controlled combustion air damper; 3 bi-metalic aquastat; 4 oil/gas burner; 5 start-up damper; 6 water walls with outside insulation and steel casing; 7 ash drawer box.

3.1.4.2 Dual Fuel Boiler With Two Fireboxes

Concept

These boilers have two combustion chambers (1 and 2), each of them designed specifically for the characteristics of the two fuels applied. The two chambers are positioned either beside each other or stacked with the oil/gas chamber on top of the solid fuel chamber. The oil/gas burner firebox (1) is designed for complete combustion and good heat transfer and therefore is much smaller than the solid fuel chamber (2). The two chambers have a common flue (3). A damper (4) can be used for start-up (lower position). The upright position is the normal operating position . Wood is burned in cross-draft. Air enters through a combustion air damper under the grate. Vertical water filled panels (6) act as principal heat exchangers directly exposed to the combustion gas stream from both chambers. A domestic hot water coil (7) is very common in dual fuel boilers.

Applications

These boilers are used in new, single family dwellings, or as replacement for oil-or gas-fired boilers. Capacities range r. from 76 to 295 MJ/hr.

Manufacturers

Tarm, Hoval, CTC

Comments

The advantage of having two seperate fireboxes to burn liquid or gaseous fuels with solid fuels is higher efficiencies when using oil or gas. The firebox design for solid fuels is the same as in the previously described boiler types.

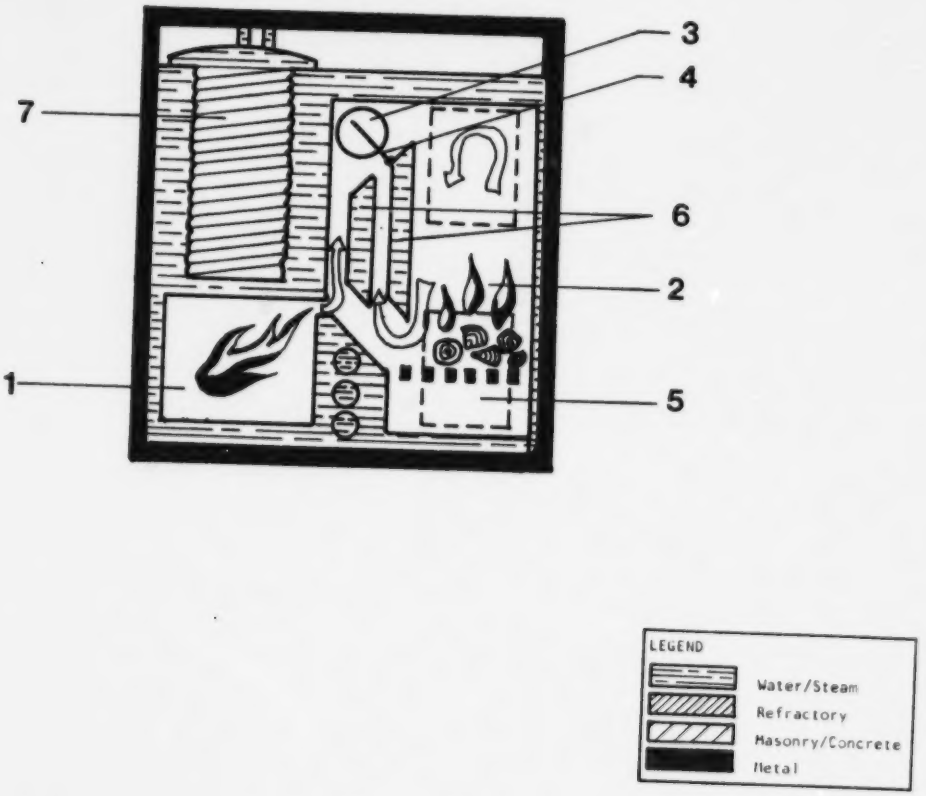

Figure 10. Dual Fuel Boiler with Two Fireboxes: 1 combustion chamber for oil or gas burner; 2 combustion chamber for solid fuels; 3 flue connector; 4 start-up damper; 5 lower door with thermostatically controlled air damper; 6 vertical heat exchange panels.

3.1.4.3 Wood-Fired Central Heating Boiler

Concept

This boiler type is basically the same as the one described under 3.1.4.1 except that it is operated on solid fuels only. Fuel is loaded through the upper front door (4). A cross-draft is created between the combustion air damper (2) and the combustion gas passage through the first water wall baffle. The combustion air damper is opened and closed by a bi-metallic aquastat allowing control of the boiler water temperatures within close limits.

Applications

These boilers are used in residential, single family dwellings, from 60 to 1,420 MJ/hr capacity.

Manufacturers

Hoval, CTC; combined with cookstove:Tiba

Comments

The principles used in this basic design are well accepted. The cross-draft concept allows the stacking of fuel in the boiler, without creating excessive firing rates. The only wood burning is that which has reached, by gravity, the zone in the cross-draft. The wood above that zone is pre-heated and dried. The water vapor and volatile matter leaving the wood has to pass through the hottest flame zone. This results in complete combustion of smoldering gases.

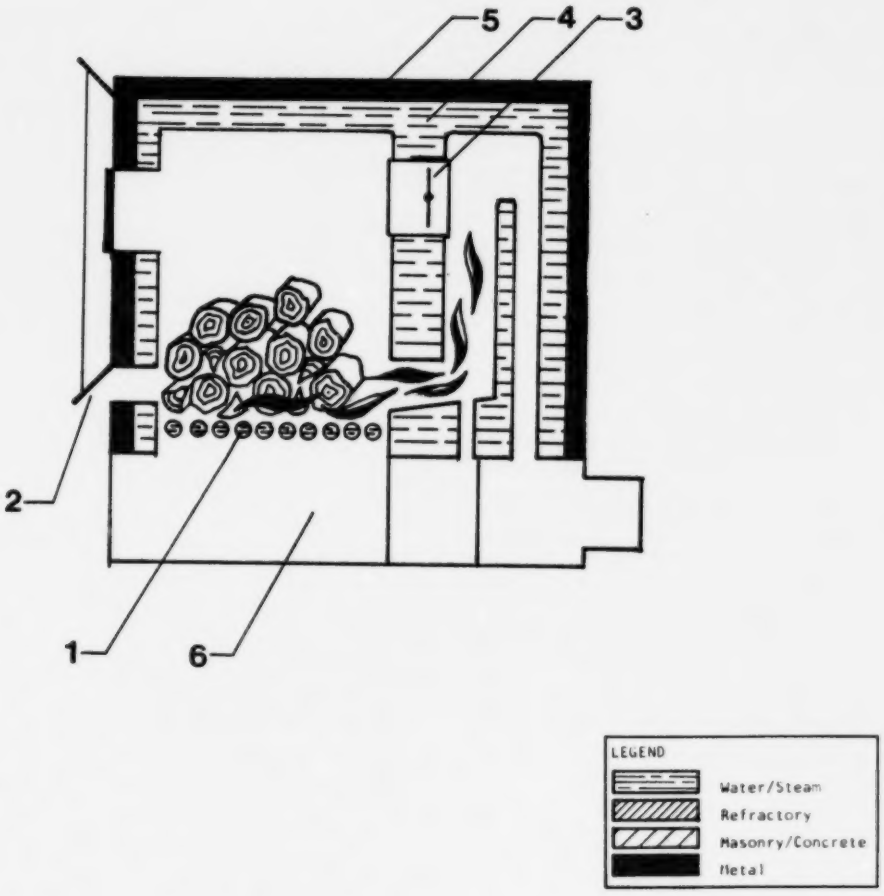

Figure 11. Solid Fuel Boiler: 1 water cooled grate; 2 combustion air damper; 3 start-up damper; 4 water walls; 5 insulation with steel casing; 6 ash drop.

3.1.4.4 Central Heating System with Domestic Hot Water Tank

Concept

In addition to the boiler parts presented in the two cases above, a seperate water tank (2) is added on top of the boiler. This tank gets heat through its metal walls from the boiler water. For summer operation an electric coil (8) is used. The boiler and tank water do not mix. Boiler water is circulated through the heating system (radiators, etc.) and back to the boiler. The domestic hot water tank gets cold water from the well or city water line. The water coming into the tank gets heated by the boiler water surrounding the tank. Instead of a tank, some boilers have a copper coil hanging in the boiler water acting as a heat exchanger.

The combustion chamber presented in Figure 12 has a slightly different combustion air guiding system (1) than the boiler already described. The combustion air is introduced into the firebox from two opposite sides above the grate.

Applications

These systems are used in single family and small, multi-family dwellings. Capacities range from 60 to 146 MJ/hr.

Manufacturers

Hoval, CTC, Tarm

Comments

The electric coil allows the house owner to avoid inefficient operation of the boiler in the summer months. In order to get domestic hot water generated by wood, the total amount of boiler water would have to be brought up to temperature. Inefficiency would result from radiation loss and low firing rates.

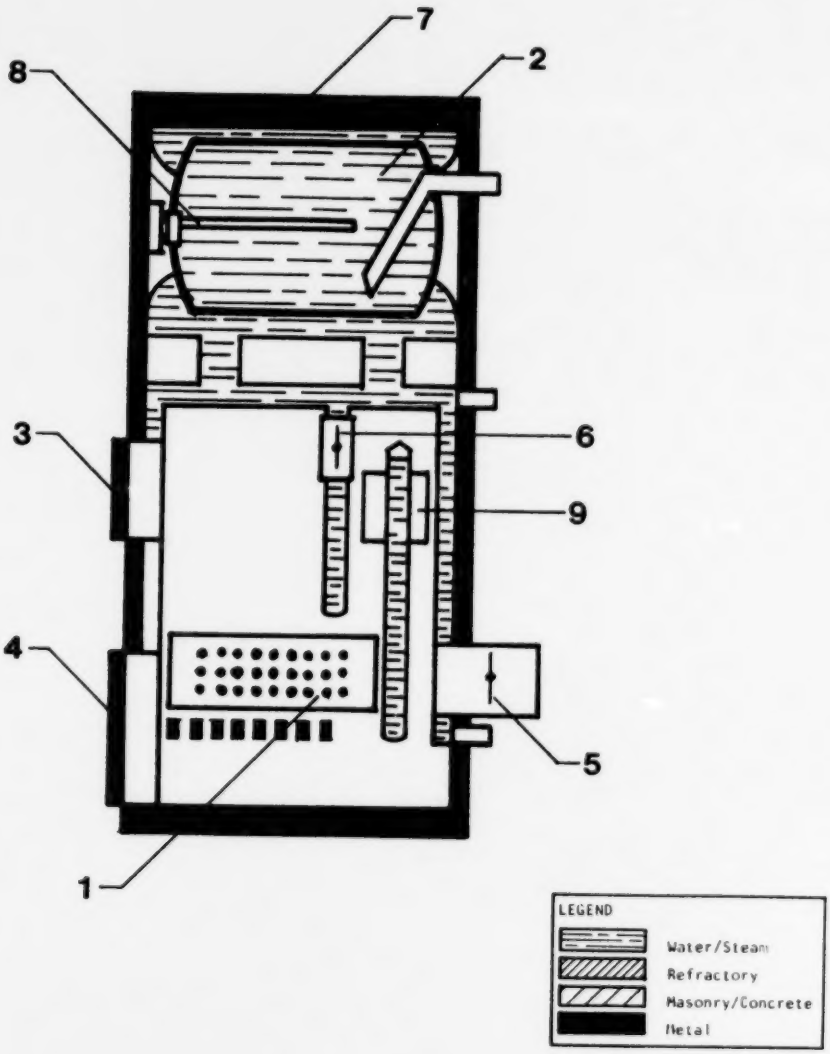

Figure 12. Solid Fuel Boiler with Domestic Hot Water Tank: 1 grate and combustion air inlets from side; 2 DHW tank; 3 charging door; 4 clean-out door with thermostatically controlled air inlet; 5 damper; 6 start-up damper; 7 insulation and casing; 8 electric element; 9 clean-out door.

3.1.5 Pre-Chamber Stick Wood Boiler

Concept

This system allows burning of stick wood. A separate chamber with a cast iron grate (1) is connected to a regular boiler (9) by a connector tunnel (6). Wood is charged through a top door (4) or through a side door (3). The wood moves down toward the grate (1) by gravity. Combustion takes place in the cross draft created between the door damper (5) and the boiler (9). Only a limited amount of air enters through the upper door (2). This air helps to move wood gases down to the grate where they are burned. The flames leap into the connector tunnel (6) where secondary combustion occurs. The pre-chamber is completely lined with firebrick (7) and has an insulated casing (8).

Applications

These boilers present excellent retrofitting possibilities for oil or gas fired boilers in residential and small commercial applications.

Manufacturers

Biowatt, Rogo

Comments

Emission data are not available, but should be similar to the wood chip pre-chamber boiler (3.1.6). The wood must be stacked very carefully into the pre-chamber to avoid bridging.

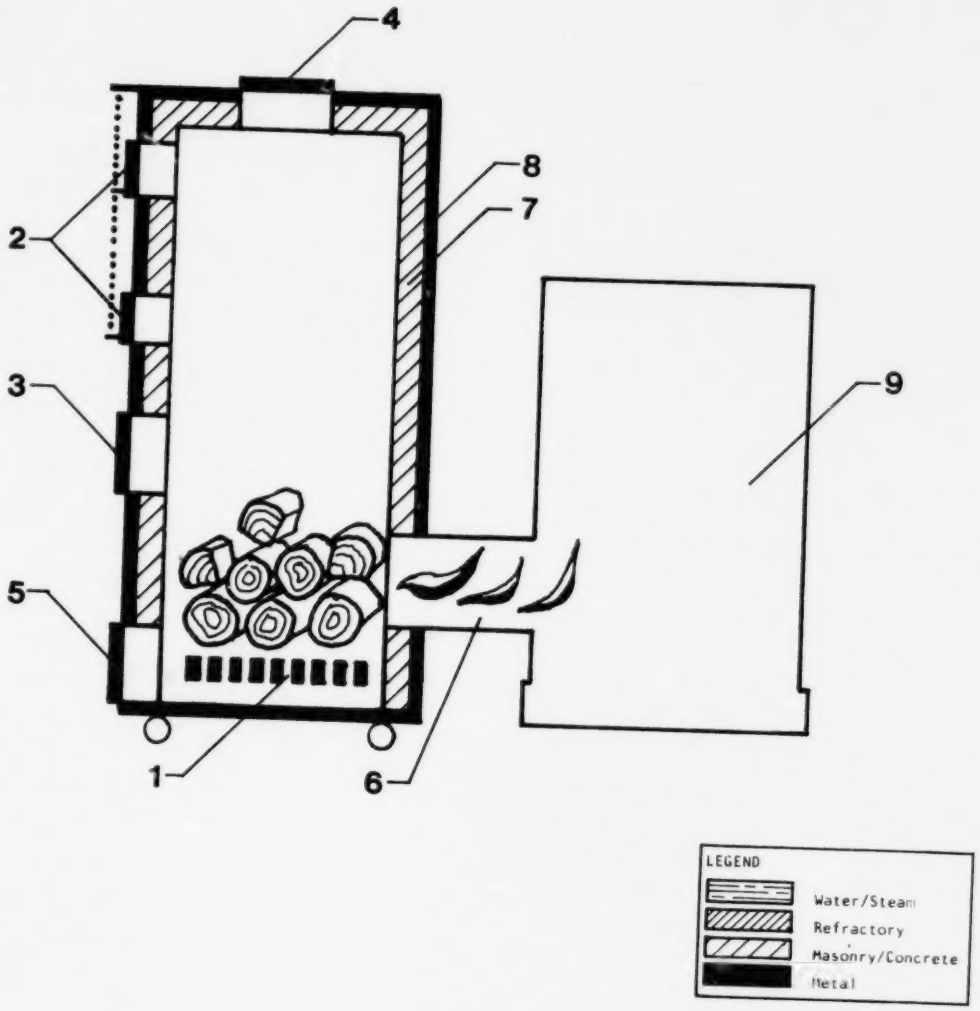

Figure 13. Pre-Chamber Stick Wood Boiler: 1 grate; 2 primary air dampers, thermostatically controlled by aquastat in boiler; 3 lower charging door; 4 upper charging door; 5 clean-out door; 6 connector tunnel; 7 firebrick; 8 insulation and steel casing.

3.1.6 Pre-Chamber Wood-Chip Boiler

Concept

The system consists of a fuel hopper (6) where wood chips are loaded from the top and travel down toward the grate (1) by gravity. A combustion air damper (3) is opened and closed by a rod-chain assembly (5). A non-electric aquastat causes the rod to turn depending on the boiler water temperature. The wood chips burn in a cross-draft between the grate and the connector tunnel (2). The combustion gases travel through the tunnel into a conventional solid fuel, gas or oil fired boiler (7), which will act as heat exchanger. Secondary air, provided through a fixed opening in the connector tunnel (4), allows remaining combustibles in the combustion gases to burn. The hopper (6) has an air tight lid and holds a supply for 1-4 days. This forces any smoldering gases to leave the pre-chamber through the combustion zone and the connector pipe.

Applications

This system is available in Sweden in capacities from 125 to 400 MJ/hr. Is is most attractive as retrofit to existing central heating hot water boilers.

Manufacturers

Iwabo System by Borgstroems Platslageri AB, Nyholm System by Thor AB.

Comments

This concept has been tested by the Swedish National Board for Environmental Protection. Air pollutant emissions in comparison with conventional grate fired boilers were considerably lower. With higher average thermal efficiency than conventional boilers, the emissions per unit heat output were even lower. Even low firing rates produce fairly high efficiencies, which is a clear advantage over grate fired boilers.

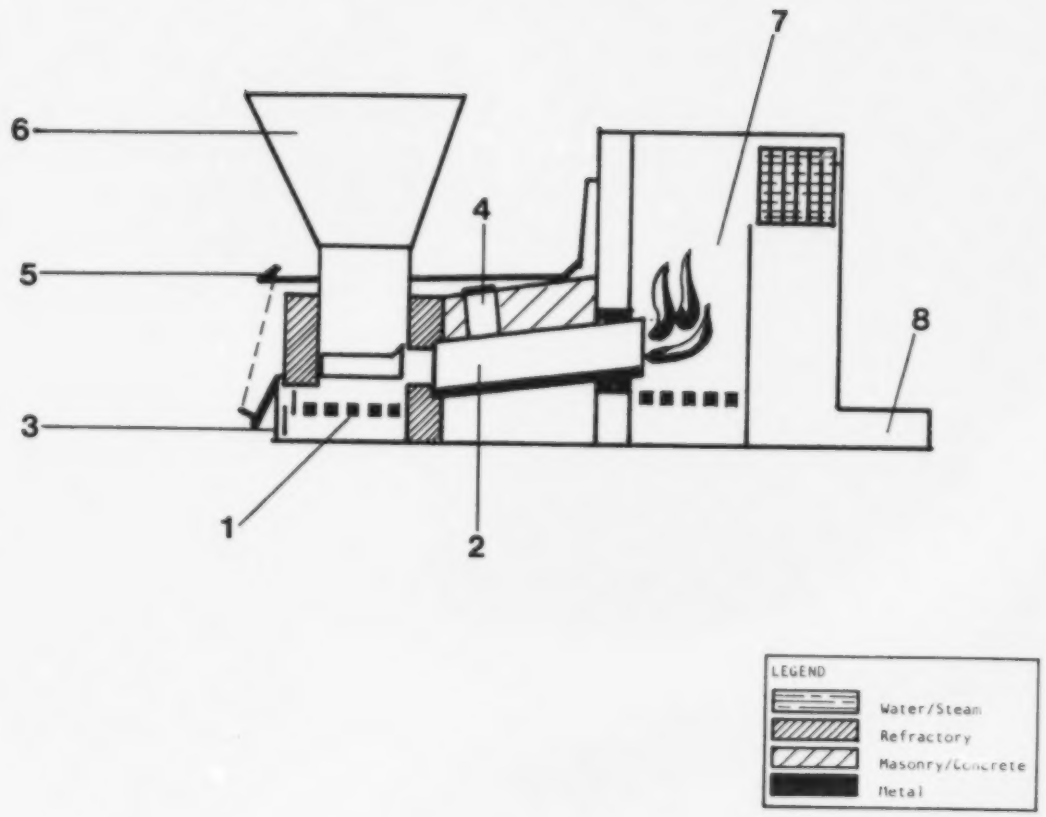

Figure 14. Pre-Chamber Wood Boiler (Chips): 1 grate; 2 connector tunnel; 3 primary air damper; 4 secondary air inlet; 5 control rod for combustion air damper ; 6 fuel hopper; 7 boiler; 8 flue connector.

3.2 COMMERCIAL EQUIPMENT

Wood working shops have created a demand for wood residue burners. These are used to burn sanderdust, sawdust, shavings, and all sizes of scrap wood. Space heating, wood dryers, and hot water needs are the most common end use categories. The great variation of fuel size created in these shops has resulted in rather complex combustion equipment design. Savings, sawdust and sanderdust are burned in suspension, whereas larger pieces of wood are fed manually and burned on a grate.

3.2.1 Combined Hand-Fired and Suspension Burner System

Concept

In this rather specialized system, sawdust, sanderdust, and shavings are introduced through a cyclone separator (7) and burned in suspension. In the cyclone the fuel particles are separated from the air, which acts as a transport medium. A specified amount of air then flows with the fuel into the combustion chamber. The surplus air is partially used as under grate air (4). Heavier particles which do not burn completely while traveling down towards the grate (3), are burned on the grate. Secondary air is introduced in the throat (5) between the main combustion chamber and the second chamber (6). In case the combustion temperature drops below the required ignition temperature for the introduced wood fires, an oil or gas burner (2) automatically supports the fire. Fuel can also be introduced through a top fuel dump (1) which has two interlocking doors. A batch of fuel would be fed into the chamber between the two doors with the lower door closed and the top door open. After the top door is closed the lower door can be opened and the fuel falls down to the grate. Primary air for the piece wood firing on the grate is introduced from under the grate (4). Secondary air is also introduced from above the passage (5) between the main chamber and the after-burner chamber (6).

The combustion gases in both operating modes are passing through firetubes equipped with turbulators (9). A draft inducer and cyclone filter are standard parts attached to these boilers in the flue connector. Ashes in most cases must be removed manually from under the grate and the flue connector (10).

Applications

This system is used almost exclusively in the wood working industry. Capacities range from 277 to 2,000 MJ/hr.

Manufacturers

Nolting, Mawera, Zima, Weiss

Comments

The great variety of different wood wastes generated in cabinetry and carpentry shops, furniture plants and sawmills made this fairly complex system necessary. Load variations are very difficult to meet with the combustion of suspended wood particles, because the minimum temperature in the combustion chamber is around 400 C. At partial load or during long on-off cycling intervals it is difficult to maintain these temperatures. Incomplete combustion and low efficiencies are the result.

Vertical heat exchange surfaces prevail over horizontal ones. Deposits which will reduce the heat transfer from combustion gases to the boiler water are claimed to be much less on vertical walls. Frequent manual cleaning of these surfaces is made easy through several clean-out openings (10 and 11). This design meets the 300 mg/m (approx. 156 ug/J input) particulate matter standard in Germany. The multi-chamber approach and the resulting long residence time of the combustion gases reduce emissions of unburnt components.

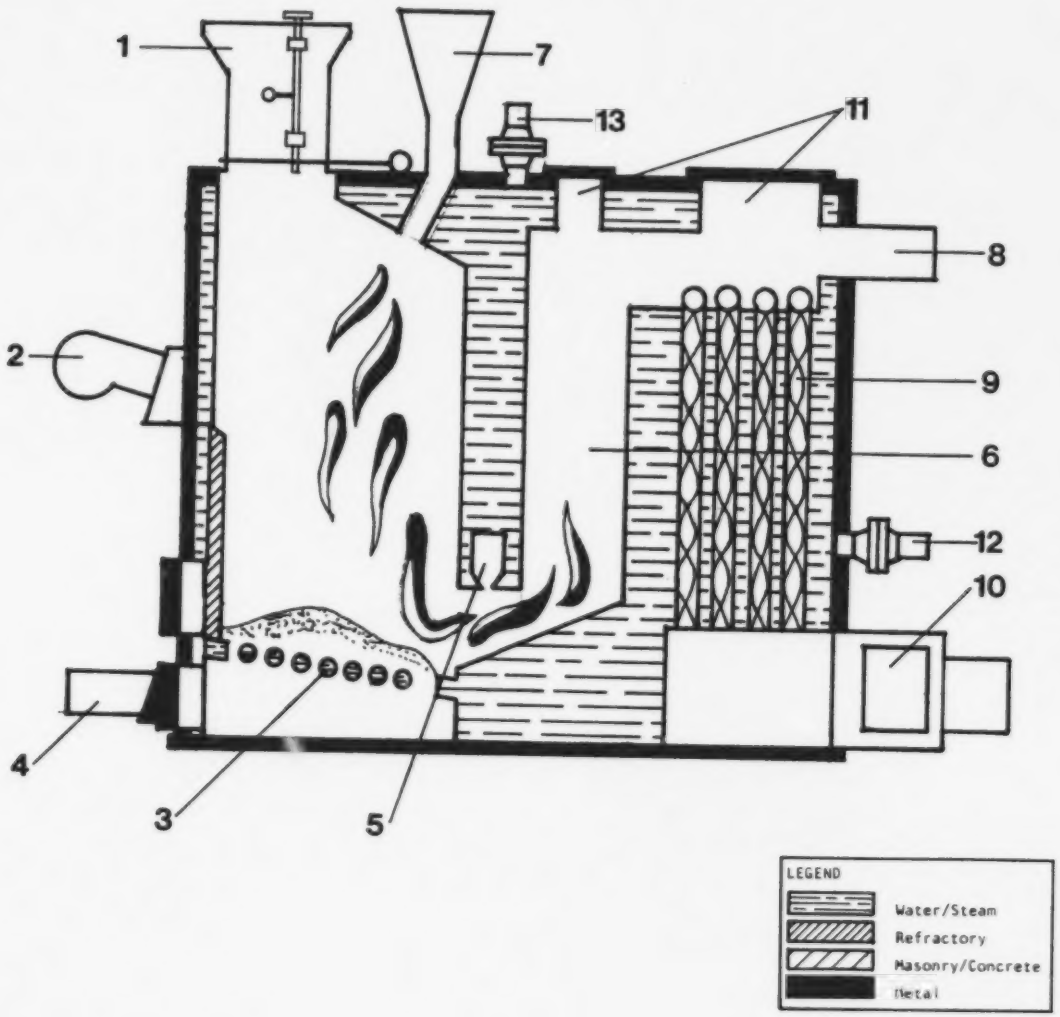

Figure 15. Hand Fired and Suspension Burner Combination: 1 fuel dump, top with inter-locking mechanism; 2 oil or gas burner; 3 water cooled grate; 4 primary air; 5 secondary air; 6 after burner chamber; 7 shaving/sander dust burner; 8 by-pass flue; 9 fire tubes with tubulators; 10 flue connection with clean-out door; 11 openings for cleaning.

3.2.2 Pre-Chamber Stick Wood Boiler

Concept

Fuel is stacked in the fuel magazine (2) through the upper door. The sticks and logs move down toward the grate (1) by gravity. Water vapor and smoldering gases escaping from the slowly heated wood cannot escape from the fuel magazine other than through the actual combustion zone. The combustion air is introduced through an air damper (4), preheated under the tilted bottom of the fuel magazine, and moves through the grate into the combustion zone. Secondary air, also coming from the inlet (4), is added above the grate. The combustion gases rise through a set of firetubes (3) in the boiler section. A flue gas damper (6) can be manually adjusted for adequate draft conditions.

Applications

This system is mainly used in wood working industries like cabinet makers shops, furniture plants and sawmills. Capacities range from 250 to 3,000 MJ/hr.

Manufacturers
Burkart

Comments

The idea of the pre-chamber set-up, where the first chamber is used as a fuel magazine, adds a considerable convenience and efficiency factor. Gravity fed and hand fed systems can only use the air supply as a means of controlling firing rates. Down-drafters and pre-chamber concepts are the only designs affecting the fuel feed rate.

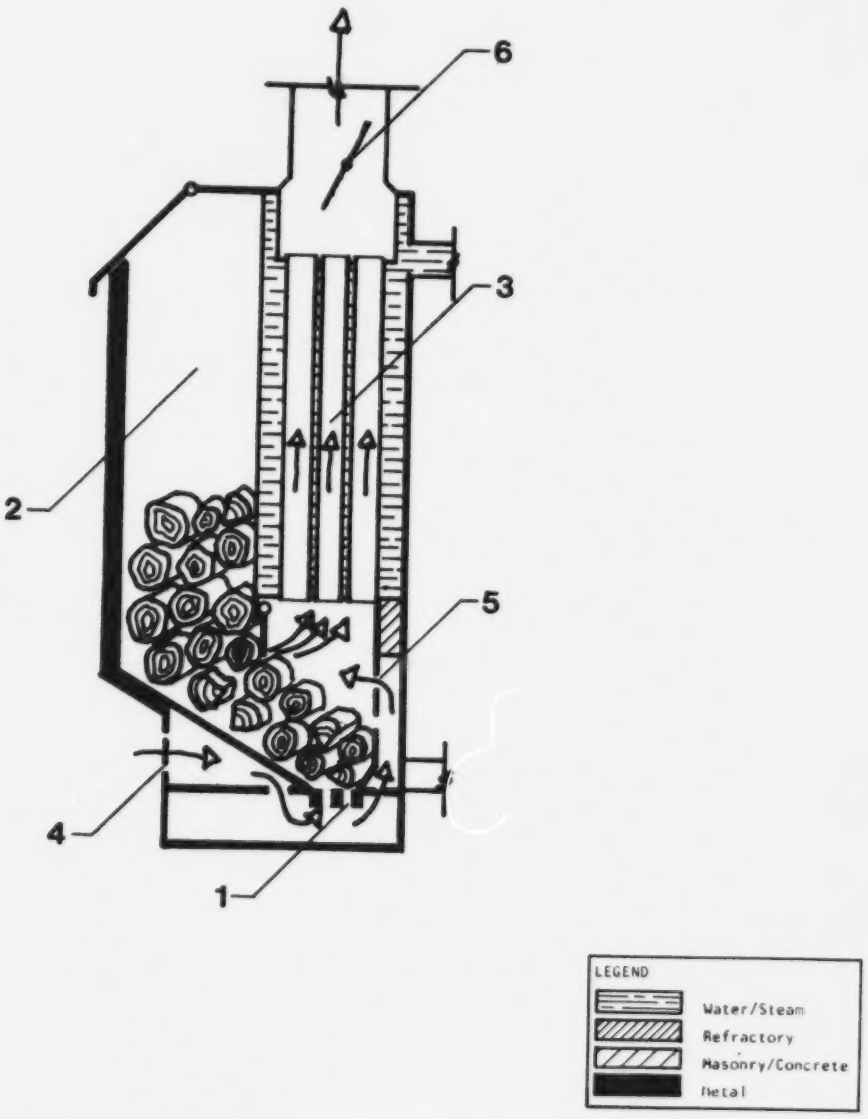

Figure 16. Pre-Chamber Stick Wood Boiler: 1 grate; 2 storage and pre-heating chamber; 3 vertical boiler section; 4 combustion air damper; 5 secondary air inlet; 6 flue damper.

3.2.3 Moving Grate Wood Chip Boiler

Concept

A screw conveyor (1) carries the wood chips from the hopper outlet (2) into the combustion chamber (4). The chips are shifted from the conveyor screw onto several parallel rigged, smaller pitched screws (3) which form a horizontally moving grate. Through the hollow core of these grate screws, combustion air is preheated and injected upwards into the fuel bed. At the dicharge end ashes are dropped into an ash box (9). The combustion gases, after passing through a set of baffles, release their heat into a firetube boiler (5). A draft inducer (6) helps to move the combustion gases through a set of multi-cyclones and out the chimney. These are all of the design details available on this brand new system.

Applications

These boilers are used in commercial and institutional heating systems. They fire best with chips and mixtures of chips and sawdust. Capacities range from 1,400 to 6,000 MJ/hr.

Manufacturers

Weiss

Comments

The manufacturer responded to the demand for less operating and maintainance intensive equipment. High efficiencies and low particulate matter emissions are claimed by the manufacturer. It definitely meets the German standard of 300 mg/m or 156 ug/J.

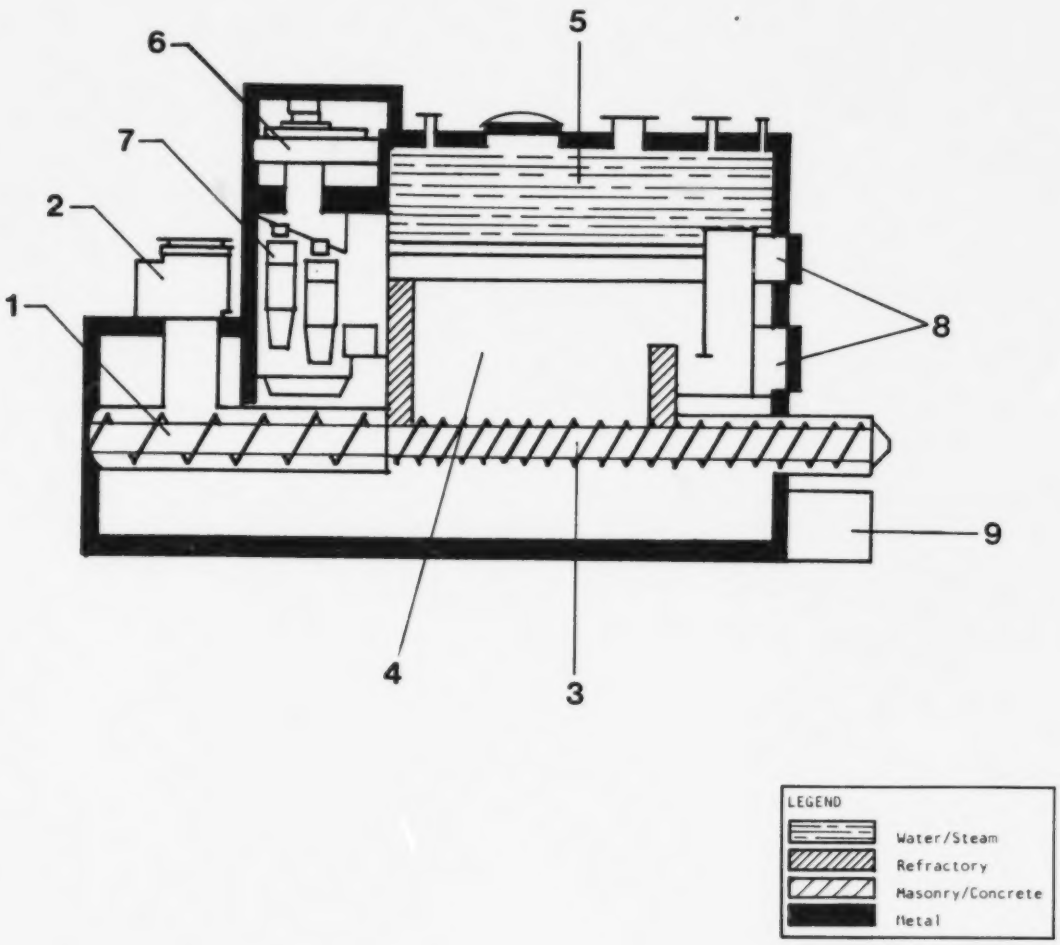

Figure 17. Moving Grate Wood Chip Burner: 1 fuel charging screws; 2 fuel hopper with sluice; 3 grate and ash carry out screws; 4 firebox; 5 fire tube boiler; 6 ID-fan; 7 multi-cyclone; 8 clean-out doors; 9 ash box.

3.3 Industrial Equipment

The larger combustion installations are either located in industrial or utility plants, including district heating plants. Wood fired boilers are most often found in the pulp and paper and in the wood working industry. A more recent application for wood fueled boilers is in district heating or public cogeneration plants in areas where wood waste is available.

There are only a few major manufacturers of industrial size wood fired boilers in Germany, Switzerland, and the Scandinavian countries. There, specialization in wood and/or other solid fuel fired equipment has brought them international recognition.

3.3.1 Retort, Stoker Fed Boilers

Concept

This design is adapted from earlier coal burning equipment. Fuel is forced by a conveyor (5) screw into a retort (7) where the wood chips are pushed upward. The resulting fuel pile burns from the top. Smoldering gases rise through the fuel bed and are burned in the hottest combustion zone. A fan (6) provides combustion air into the fuel bed through a series of holes in the retort walls. Secondary air is introduced above the fire (9). The boiler (8) can be a water wall or fire tube boiler. Figure 18 shows a very typical fuel storage and conveying design. It is used with a wide variety of combustion equipment, not just the retort, stoker boiler. A cylindrical metal or concrete silo (1) holds the chips. Two coveyor screws sweep the silo floor constantly rotating around the central out-feeding mechanism. The chips are pulled towards the central opening and drop down to the screw conveyor (3). Before the chips get into the stoker screw (5), they pass through a rotary valve (4) which provides a positive seal between the stoker screw and the silo discharge screw. The ashes are to a large extent carried out through the boiler and are collected from the flue gases in multi-cyclone filters (not shown). Periodic manual clean-out is necessary.

Applications

These boilers are used in medium size space heating and process heat installations ranging from 3,000 to 5,000 MJ/hr. Retorts can be built in older, once converted coal, fired boilers.

Manufacturers

Koehler-Bosshardt, Schmid

Comments

This design is fairly wide spread for chip burning. It is one of the best designs with a proven record of reliability. Well adjusted systems reach good efficiencies (84%). Particulate matter emissions are relatively high due to the limitations of fly-ash collection efficiency in mechanical separators. The manufacturers claim that the particulate matter passing through the boiler and cyclones is inert ash, which does not cause any negative impacts. Complete combustion in the firebox can be easily achieved if there is consistency in the fuel composition and if proper combustion air adjustments have been made.

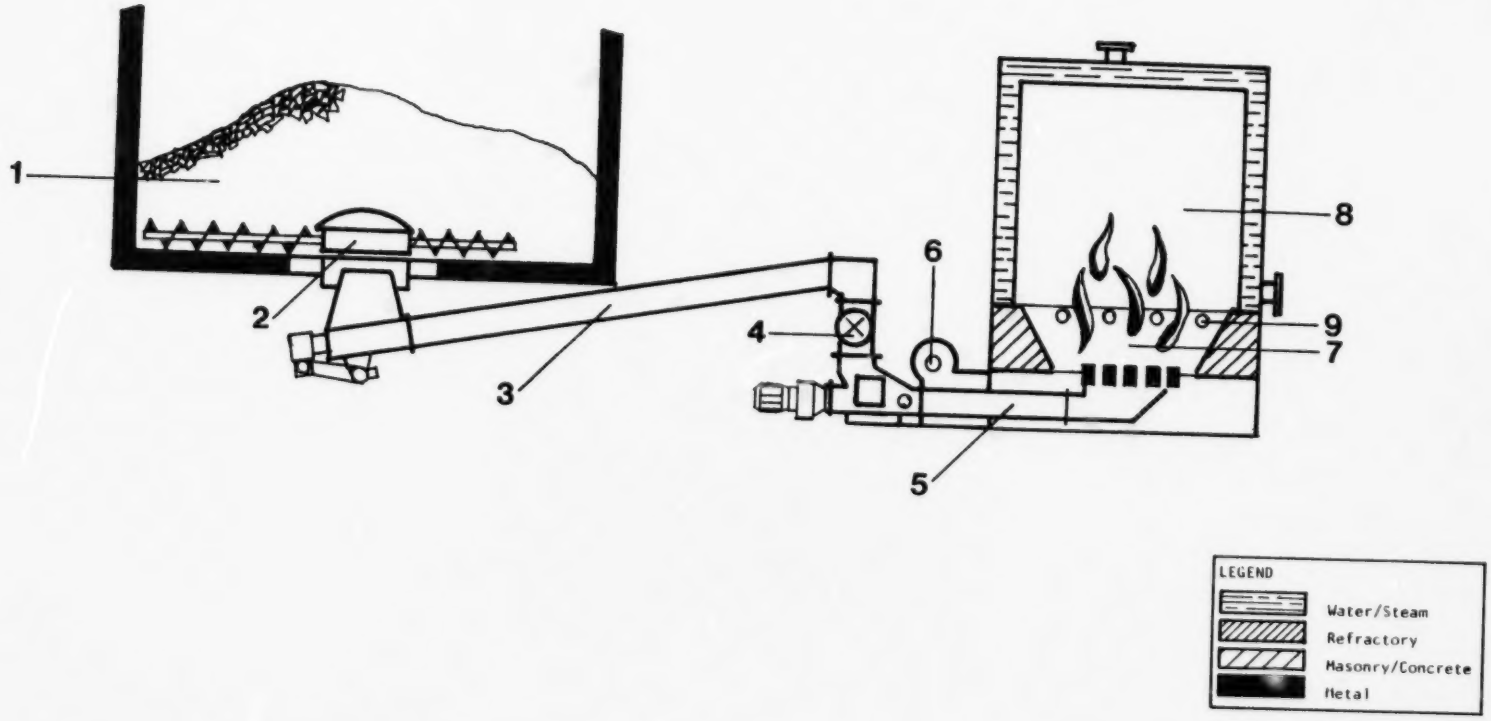

Figure 18. Retort, Stoker Fed Burner: 1 fuel storage silo; 2 fuel retrieval system; 3 screw conveyor; 4 rotary valve; 5 stoker screw conveyor; 6 combustion air fan; 7 retort; 8 boiler; 9 secondary air inlets.

3.3.2 Cyclone Burners

Concept

Cyclone burners apply the principle of centrifugal force. The fuel particles are introduced in various sizes into the bottom of a vertical, cylindrical combustion chamber with a hydraulic ram (1). Primary air is injected through a series of holes in the bottom of the chamber (2). Secondary air (3) is introduced tangentially producing a swirling motion. Suspended, the burnt fuel particles are trapped by the centrifugal force in the space along the chamber walls. Only the lightest particles, consisting of ash, will be able to move out into the vertical combustion gas stream going into the boiler.

Applications

These burners are used for industrial systems from 1,000 to 50,000 MJ. They can be retrofitted and cofiring with oil or gas is possible. They burn a variety of wood sizes and moisture contents.

Manufacturers

Konus

Comments

Cyclone burners are quite common in Europe and are known for their efficiency and reliability. Their good performance seems to be a result of a combination of grate and suspension combustion. These are also the features which allow the wide variation in fuel characteristics. The firebrick lined combustion chamber reaches high temperatures reducing CO and HC emissions. Particulates can be a problem, however, and control devices (multi-clones) are required.

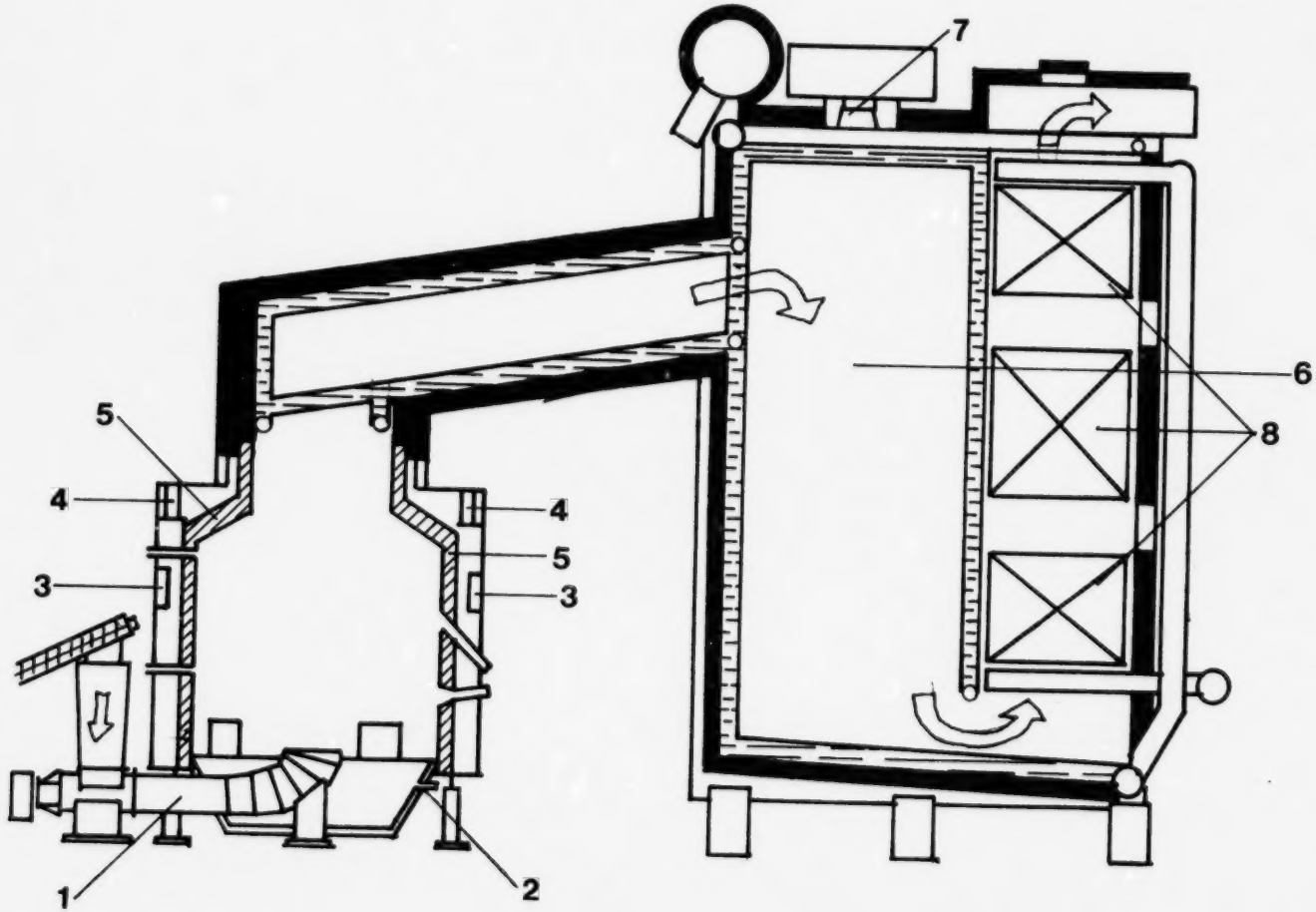

Figure 19. Cyclone Burner: 1 hydraulic ram; 2 primary air through air holes on furnace bottom; 3 secondary air supplied tangentially; 4 tertiary air, supplied tangentially; 5 firebrick lining; 6 boiler; 7 vertical oil/gas burner back-up; 8 economizers.

3.3.3 Fluidized Bed Combustor

Concept

An inert material is kept in suspension in the bottom (1) of a tall membrane wall vessel. Primary air is introduced from the bottom (3) at high velocity. The bed material, normally a quartz or limestone granulate, is kept in suspension. The wood fuel is introduced into the densest portion of the bed. The wood particles are also kept in suspension. Each individual fuel particle is surrounded by mineral particles. This micro-environment, after the system has been initially heated up by an auxilliary oil or gas burner (7) to ingnition temperatures, offers ideal combustion conditions for the fuel particle. The mineral particles reflect the heat generated by the burning wood pieces and therefore allow very high combustion temperatures. Once the wood particle gets lighter, it moves upwards in the combustor and is finally carried out of the membrane wall boiler (4) as ash. Some amount of bed material is also traveling to the top of the combustor but is then trapped in the hot cyclone (5) and returned to the bottom of the combustor. Most of the ash will also be trapped by the cyclone and will collect at the bottom of the combustor.

There are different types of fluidized bed combustors. A fixed bed combustor keeps the bed material in the bottom third of the vessel, the agitated bed combustor allows bed material to move up and down the lower half of the vessel and the circulating bed or fast bed combustor which has been described above.

Applications

These systems are used for commercial and industrial small to large size systems (1,000 to 50,000 MJ/hr). Retrofit of existing oil and gas fired systems is possible if space is available.

Manufacturer

Ahlstrohm

Comments

Even though the fluidized bed combustion technology has been primarily developed for coal, it offers advantages over other wood fired equipment. The system is not very sensitive to unhomogeneous fuel composition. Since each particle is burned in its own micro-environment, variation in moisture content and grain size has no significant effect on combustion efficiency, e.g. a district heating system in Eksjo, Sweden is equipped with a fluidized bed combustor. During the morning hours each day municipal solid waste is burned, while in the afternoon and evening hours wet bark and wood chips are fired. This switch

over from one fuel to the other does not make major adjustment necessary. Emissions of particulate matter in the Eksjo case are extremely low (29 ug/J). The system also contains a baghouse, which certainly makes its contribution to the low emissions.

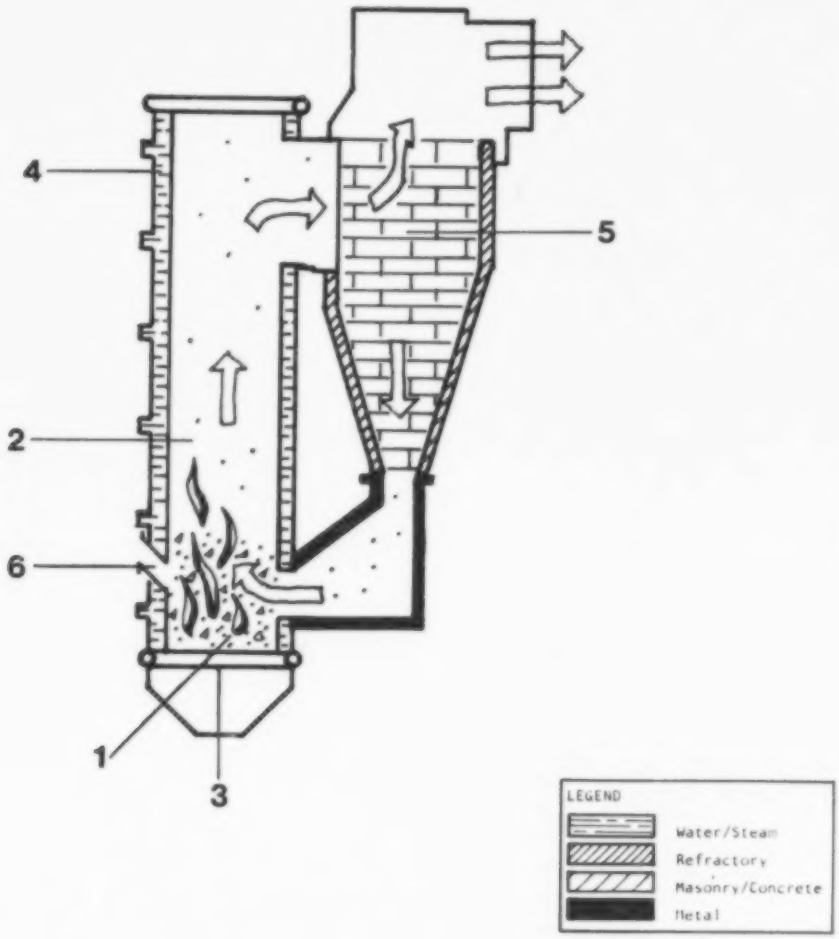

Figure 20. Fluidized Bed Combustor (Fast Bed): 1 inert material forming fluidized bed; 2 secondary air inlets; 3 primary air jet inlets; 4 membrane wall boiler; 5 hot cyclone; 6 fuel feed.

3.3.4 Inclined Moving Grate Boiler

Concept

Fuel is introduced into the combustion chamber (2) through a fuel drop (4) equipped with a set of sluices. The fuel falls on a long step grate (1). Gradually the fuel is heated as it moves down the grate. Moisture and then volatile matter are released. At the end of the step grate more and more combustion air is supplied through the grate. The flames above the grate move downwards to the lower end of the combustion chamber and then return counter current along the refractory ceiling (11) upwards toward the boiler section (7). Secondary air is introduced just below the throat at the top of the combustion chamber. The flames returning from the lower end of the combustion chamber radiate intensive heat downwards toward the fuel ladder grate. The combustion gases pass through a firetube boiler, also equipped with an auxilliary oil burner (10). A multi-cyclone and induced draft fan (9) are standard equipment with this type of combustion system. Ash falls through the grate into a set of ash hoppers from where it is moved by a screw to an ash dump.

Applications

These boilers are used in the pulp and paper industry for the burning of wet bark and sludge. Capacities range up to 16,000 MJ/hr.

Manufacturers

Lambion, Weiss

Comments

This combustion equipment has been developed over the last twenty to thirty years for the combustion of wet bark. The very low particulate matter emissions can be attributed to the relatively long residence time of the fuel in the system. Also the very effective drying power of radiant heat created by the counter current flames and the refractory walls make a contribution to complete combustion and therefore low emissions of unburnt substances.

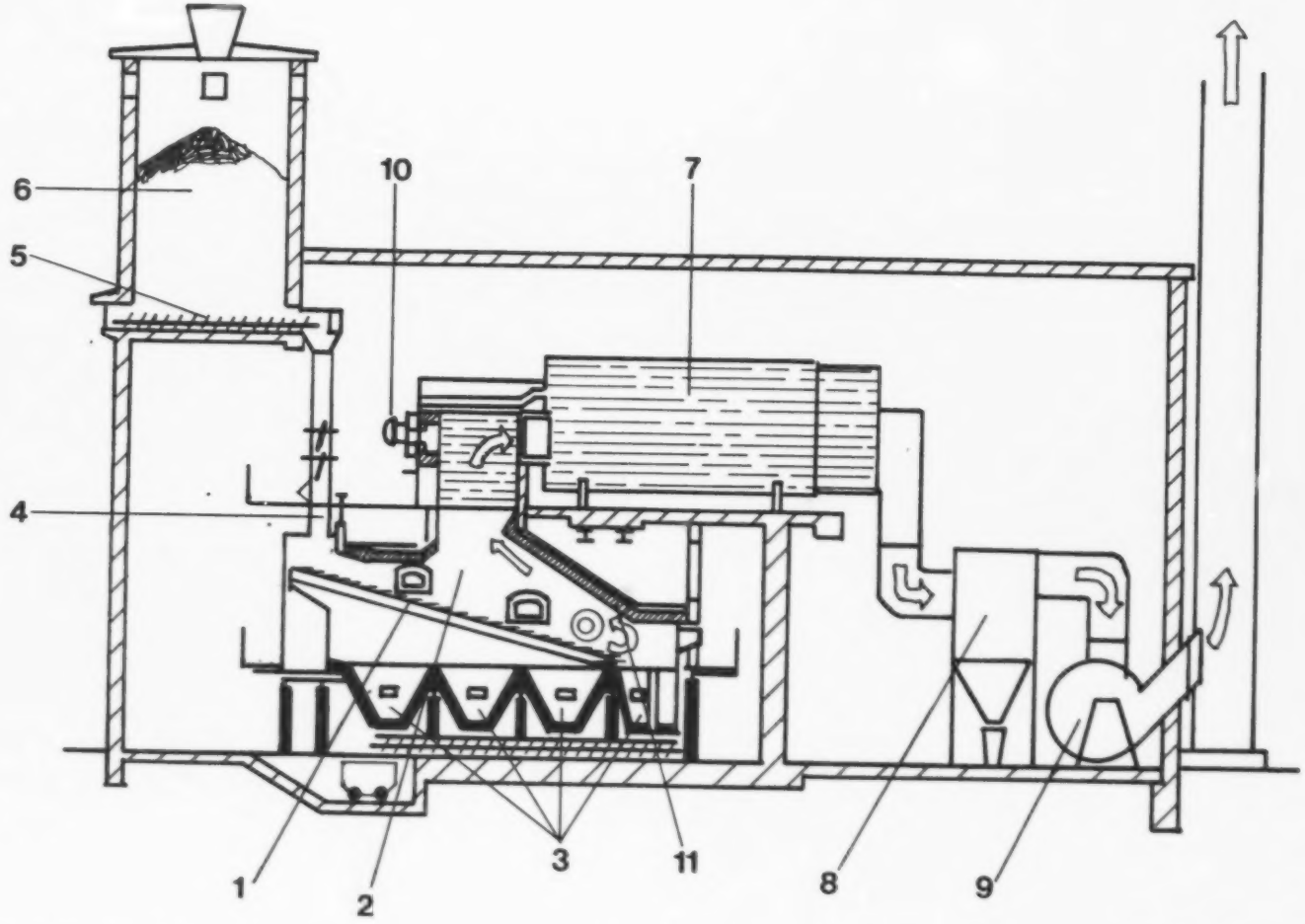

Figure 21. Inclined Moving Grate: 1 reciprocating grate; 2 combustion chamber; 3 ash catchers; 4 fuel drop with sluices; 5 silo discharge screw; 6 fuel silo; 7 fire tube boiler; 8 multi-cyclones; 9 ID-fan; 10 auxilliary burner.

3.3.5 Wood Waste/Suspension Combustion Boiler

Concept

This design includes not less than four fireboxes. Above the first grate (1) combustion of piece wood takes place. In the firebox above the second grate (2) wood fires are burned in suspension. A start-up and support burner (7) is attached to a conical refractory lined chamber. The fourth combustion chamber (5) is positioned on top of the second one. It is also equipped with a gas or oil burner. This chamber allows complete burn-out of unburnt fires carried over from the chambers below. The combustion gases of all chambers finally reach a firetube boiler (6) and are discharged through a multi-cyclone and ID-fan into the stack. Combustion air is introduced through the suspension burner and through both grates (1 and (2).

Wood waste can be charged either through a shaft (3) or through a wood fire suspension burner (4). Ashes fall through the grate into ash boxes or have to be cleaned out through the various clean-out access doors.

Applications

These boilers are used in larger furniture plants and other wood working industries. Water and steam is produced for space heating and drying heat for kilns. Capacities range up to 42,000 MJ/hr.

Manufacturers

Weiss

Comments

Apparent again is the built-in flexibility of one piece of equipment in handling various grain sizes of fuel. Relatively little heat exchange surface (water tubes) is placed directly in the firebox. This avoids early generating of unburnt or partially unburnt gases and particles. The other apparent feature of this design is the long pathway, or the long residence time, of the combustion gases in the equipment. This allows time for complete burn-out.

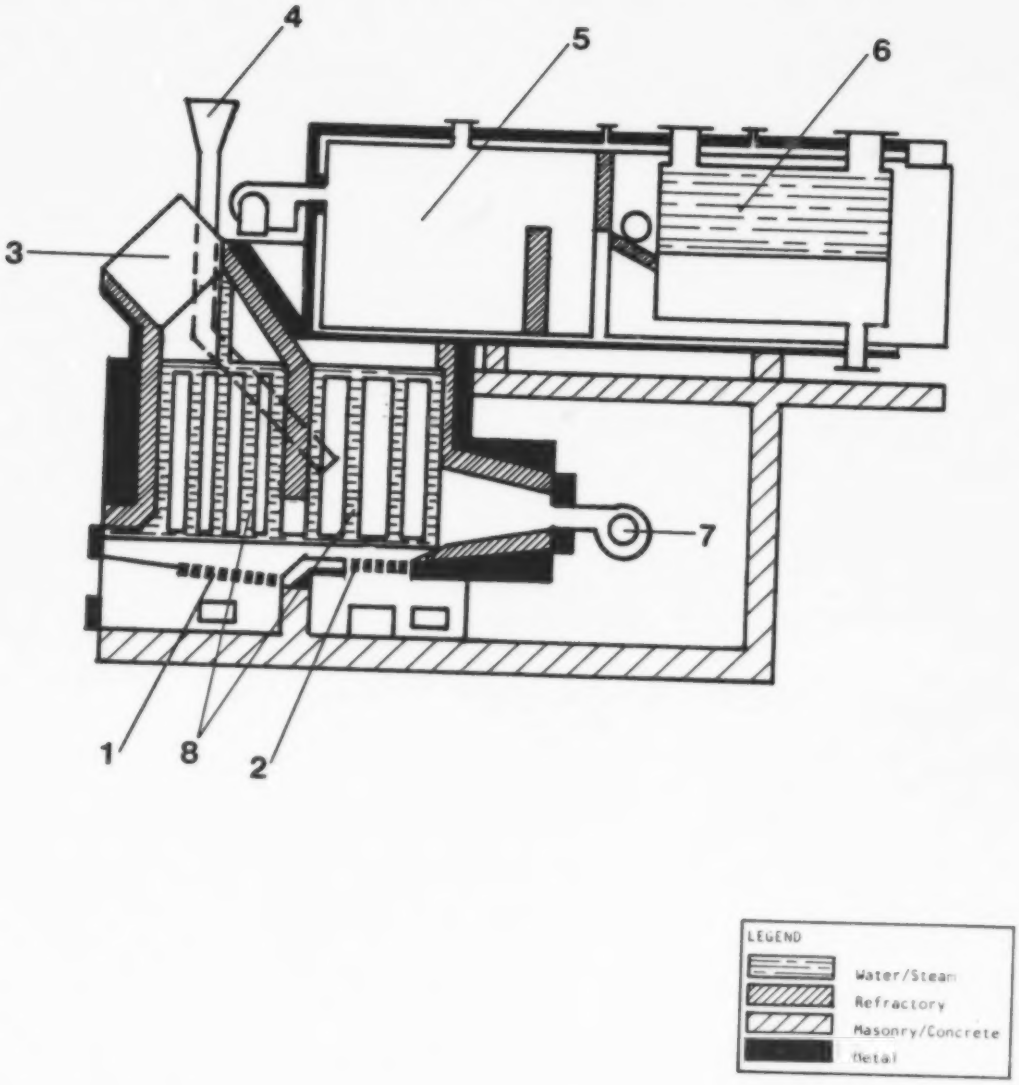

Figure 22. Wood Waste/Suspension Combination Boiler: 1 grate for coarse wood waste; 2 grate of suspension burner chamber; 3 wood waste charging door for containers; 4 wood dust charging line; 5 upper combustion chamber with auxilliary burner; 6 boiler; 7 oil/gas burner; 8 water tubes.

3.3.6 Pre-Chamber, Batch-Fed, Water Tube Boiler

Concept

The two major components are the combustion chambers (1) and (2) and the compact water tube boiler (5). An ideal arrangement is the vertical separation of the firebox and the boiler, as shown in Figure 23. The firebox and the water tube boiler are completely lined with refractory. The firebox, often referred to as pre-chamber, consists of two sections. The first section (1) receives the wood fuel through a door (3). A baffle wall (8) partially separates the first from the second section. Secondary air is introduced from under the grate of the second section. The combustion gases rise up into the water tube boiler (5). An auxilliary burner (6) is capable of providing additional heat input into the boiler or can take over low loads. Ashes drop through the two grates into ash boxes.

Applications

These boilers are mostly used in wood working industries where wood waste in various grain sizes is available. Capacities range from 1,7000 to 13,000 MJ/hr.

Manufacturers

Weiss

Comments

The fireboxes are again only moderately cooled by sparsely placed water tubes. The whole structure is refractory lined. This allows high combustion temperatures. These boilers have built-in soot blowers and generally require multi-cyclones to meet German particulate matter standards.

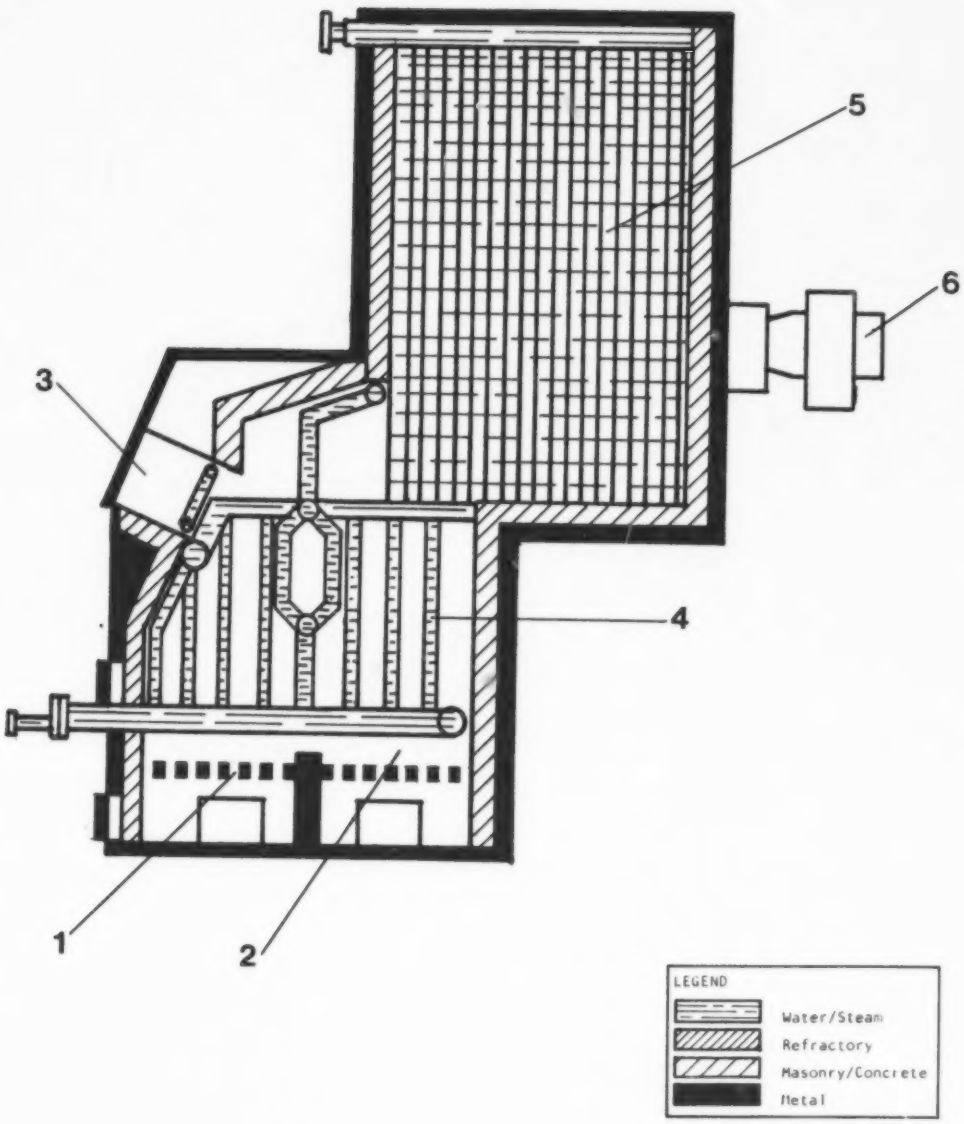

Figure 23. Dutch Oven Type Boiler: 1 fixed grate system, primary; 2 secondary grate; 3 charging door; 4 water tubes; 5 boiler section; 6 auxilliary burner.

3.3.7 Wood Gasifiers

Wood gasifiers were used in Europe, especially in West Germany, Switzerland, and Sweden, during the second World War. There is definitely a renaissance of gasifier use taking place now, but some of the short-comings of this type of system that people accepted under war conditions now have to be corrected. These disadvantages include better handling of fuel and residues (condensables). Most of the units under development are connected with an internal combustion engine. The philosophy is that gas, as a high quality energy source, should be used to produce electrical or mechanical power rather than heat.

Gasifiers exist in basically three different forms in Europe. Figure 24 shows these basic design differences. From left to right there are up-draft, down-draft, and cross-draft systems. Also, as in Figure 25, differences in the wall construction can be pointed out. Again from left to right, a single wall, a double wall, and a double wall with condensator construction.

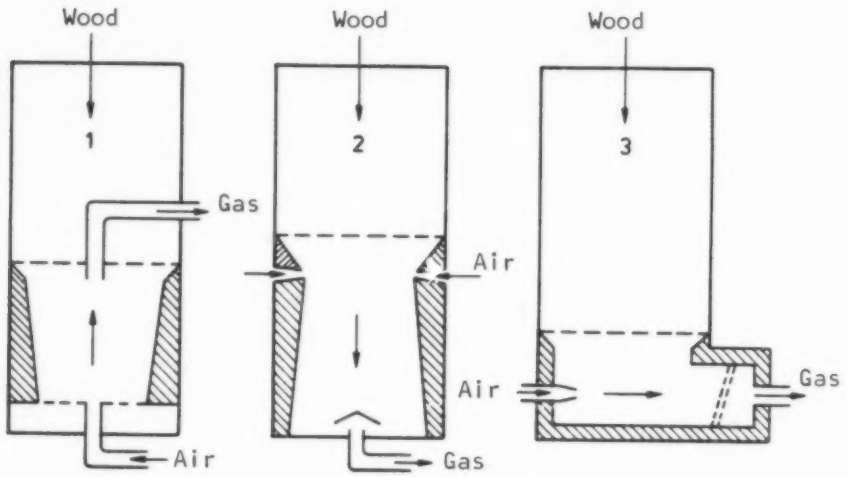

Figure 24. Gas Flow in Wood Gasifiers:
Counterflow
Down-Drafter
Cross-Drafter

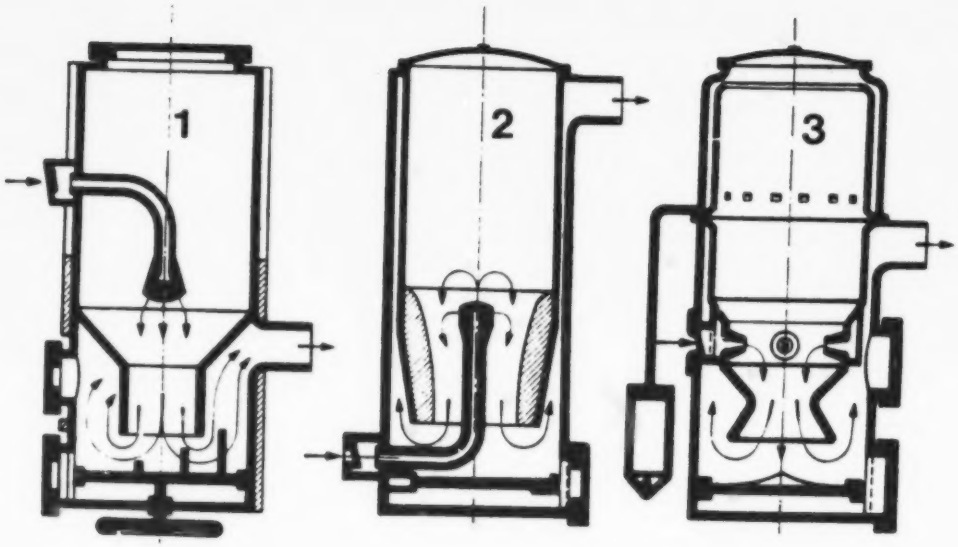

Figure 25. Combustion Differences of Down-Draft Gasifiers:
1. Single Wall
2. Double Wall
3. Double Wall and Condenser

3.3.7.1 Stationary Wood Gasifier Generator Set

Concept

The firebrick lined gasifier is charged with wood chips and shavings from the top through a wet of sluices (3). The hottest zone (14) is created by the introduction of a controlled amount of combustion air to a limited area at the bottom of the gasifier. The heat generated in that area rises and creates a temperature gradient from this area toward the top and outside wall of the gasifier. A by-pass stack (15) is used for start-up and burn-out. The wood gases leave the gasifier through a gas line on top and are cooled in two fan-driven coolers (6). The gases then enter the bottom of a filter system consisting of a wooden grate (9), wood wool filler (10) and wood chips (11). The cleaned and cooled gases are normally pulled out of the gasifier and through the cooler-filter assembly by the aspiration of the internal combustion engine. The gases are consumed by such an engine. Depending on speed and load of the engine the necessary amount of gases is pulled through the system.

The condensates formed in the gas cooler (6) flow down into a condensate tank (8) where tar like substances accumulate in the tank bottom (7). The engine produces mechanical power for direct drive of pumps, compressors or other equipment, and in most cases,an electricity generator.

Applications

Most applications for gasifier generator sets in Europe are on the small to medium scale (10 to 800 kW). Favored applications are mechanical drive systems using modified gasoline or gas engines.

A wide variety of mobile and stationary applications were in place during World War II in many European countries.

Manufacturers

Lambion, Roth, Duvant

Comments

Several gasifier systems in Europe are undergoing tests for efficiency, reliability, and convenience. The Lambian test data show a lack of efficiency. No significant improvements were achieved by injecting water. Some emission data for the gas engine are included in Table 2. One interesting concept found in the Swiss Alps uses a wood gasifier in connection with a cogeneration system. A small village (Sent) has a project under way to use a central cogeneration system to generate heat and electricity for the community. Internal combustion engines would be used to either drive heat pumps or generators, and the heat from the engine cooling and exhaust system would be mixed with water coming from the heat pump. The hot water would be piped to all houses in the central part of the village.

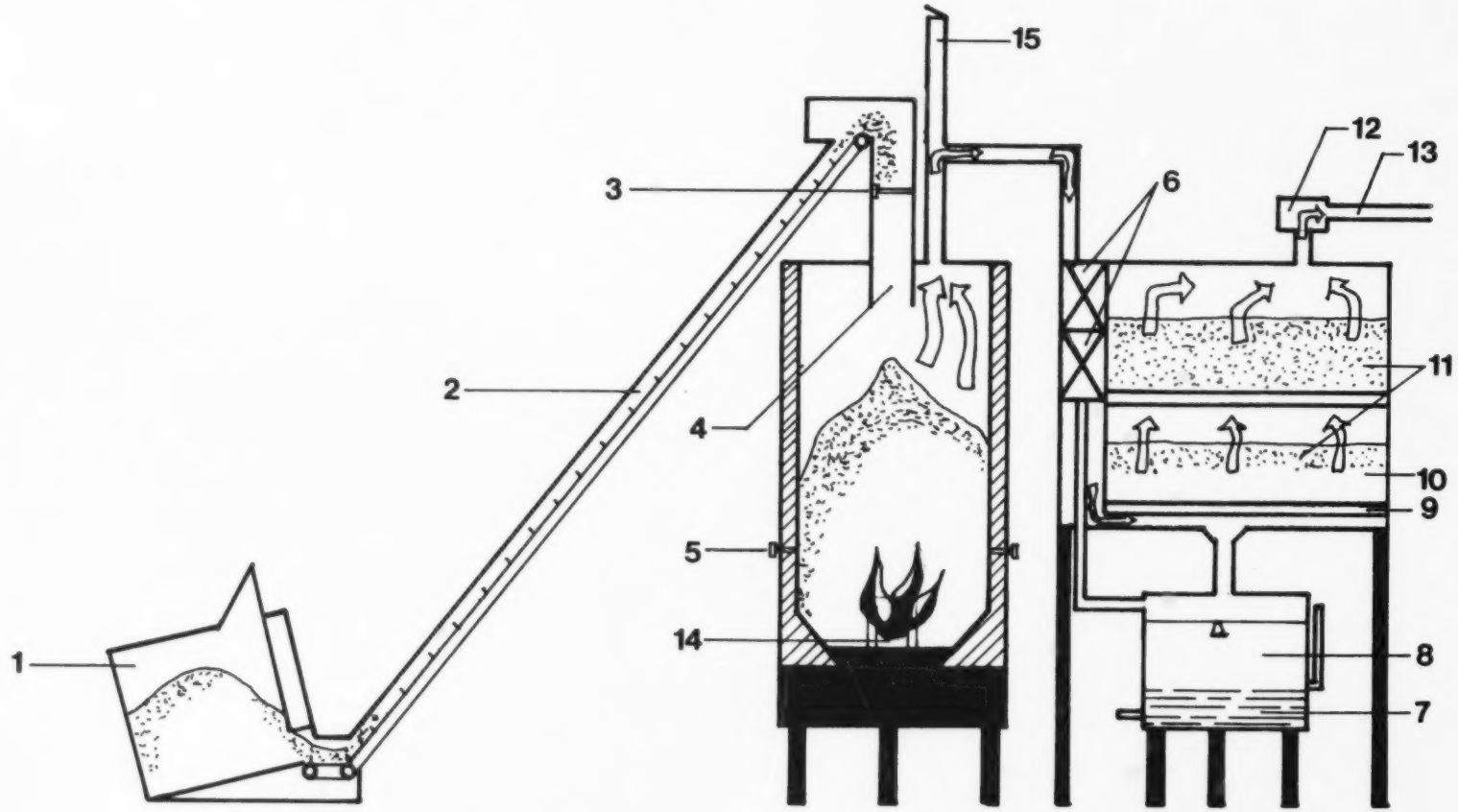

Figure 26. Wood Gasifier: 1 wood shaving storage hopper; 2 conveying system; 3 sluice; 4 wood level sensor; 5 water injector; 6 two ventilators - gas coolers; 7 tar; 8 condensate; 9 wooden grate; 10 wood wool; 11 wood chips; 12 fan; 13 gas line to I/C engine; 14 limited combustion zone; 15 by-pass stack.

3.3.7.2 Compact Gasifier-Generator Set

Concept

The principal equipment types involved are (1) a down-draft gasifier, (2) a gas cooler and cleaner, (3) an internal combustion engine, and (4) an electro-generator. A stationary version is shown below the two mobile units. This larger installation has some additional parts, like a cyclone filter and an automatic fuel feed mechanism (9 and 10).

The down-draft gasifier is an improved version of the once most widely spread vehicle wood gasifiers in Central Europe. The design corresponds approximately to unit number 3 in Figure 25. The combustion process in the gasifier is limited to the bottom throat area and is controlled by the amount of air introduced to that area. Once the gasifier is up to operating temperature the gas production is controlled directly by the suction created by the internal combustion engine. Any speed or load variation varies the wood gas production.

Applications

These gasifier-generator sets are used for remote power generation in Third World Countries. There are potential applications in the commercial and industrial sectors for cogeneraiton, and as compressors on pump drives. Capacities range from 10 to 60 KVA for mobile units and from 50 to 200 KVA for the stationary installations.

Comments

The basic technology used was proven effective in thousands of applications during World War II. Virtually no further development has been done for thirty years. The revival of this technology proves not to be very easy because only a few people can still make use of their extensive experience with gasifiers. Reliability and economic feasibility has to be proven again. The manufacturer claims 30% efficiency for the conversion of thermal to mechanical energy in its gas engines. Wood gas for this type of gasifier, and by using air dry wood (20% moisture content), has yielded 4.6 to 5.5 kJ/m^3. 23% carbon monoxide, 15% hydrogen, 2% methane, 50% nitrogen, and 10% carbon dioxide make up the composition of the gas.

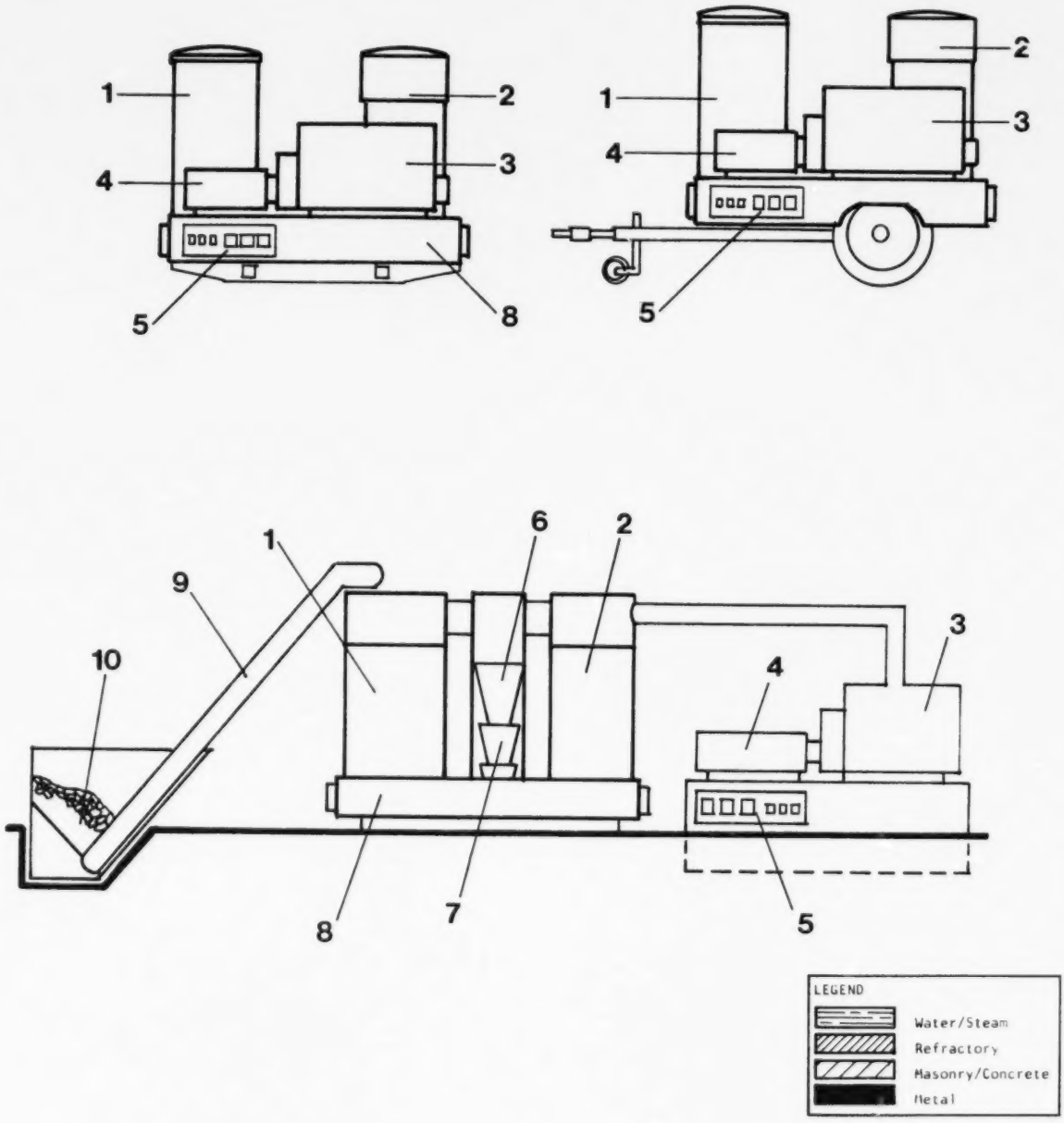

Figure 27. Compact Gasifier-Generator Set: 1 down draft wood gas generator; 2 gas cooler and cleaner; 3 I/C engine; 4 electro generator; 5 control panel; 6 cyclone; 7 collected particles; 8 support frame; 9 wood chip conveyor; 10 wood chip hopper.

4.0 REFERENCES

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20. Pott, F. and R. Dolgner. "Problems Involved in Findings on Exposure Limit for Polycyclic Aromatic Hydrocarbons". In: Proceedings of Hannover Colloquium 1979, see ref. 13.

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APPENDIX A

Conversion Table

English and Metric Units to SI Units

CONVERSION FACTORS

SI Units to Metric or English Units

To Obtain	From	Multiply By
g/Mcal	ng/J	0.004186
10^6 Btu	GJ	0.948
Btu	gm cal	3.9685×10^{-3}
lb/10^6 Btu	ng/J	0.00233
ft	m	3.281
in.	cm	0.3937
ft^2	m^2	10.764
ft^3	m^3	35.314
lb	kg	2.205
Fahrenheit	Celsius	$t_F = 9/5(t_c) + 32$
Fahrenheit	Kelvin	$t_F = 1.8t_K - 460$
psig	Pa	$P_{psig} = (P_{pa})(1.450 \times 10^{-4}) - 14.7$
psia	Pa	$P_{psia} = (P_{pa})(1.450 \times 10^{-4})$
iwg (39.2 °F)	Pa	$P_{iwg} = (P_{pa})(4.014 \times 10^{-3})$
10^6 Btu/hr	MW	3.413
GJ/hr	MW	3.60

To Obtain ppm at 3% O_2 of	Multiply* Concentration in ng/J by
Natural Gas Fuel	
CO	3.23
HC	5.65
NO or NO_x	1.96
SO_2 or SO_x	1.41
Oil Fuel	
CO	2.93
HC	5.13
NO or NO_x	1.78
SO_2 or SO_x	1.28
Coal Fuel	
CO	2.69
HC	4.69
NO or NO_x	1.64
SO_2 or SO_x	1.18

*These conversions depend on fuel composition.
The values given are for typical fuels.

English and Metric Units to SI Units

To Obtain	From	Multiply By
ng/J	$lb/10^6$ Btu	430
ng/J	g/Mcal	239
GJ	10^6 Btu	1.055
m	ft	0.3048
cm	in.	2.54
m^2	ft^2	0.0929
m^3	ft^3	0.02832
kg	lb	0.4536
Celsius	Fahrenheit	$t_c = 5/9\ (t_F - 32)$
Kelvin	Fahrenheit	$t_K = 5/9\ (t_F - 32) + 273$
Pa	psig	$P_{pa} = (P_{psig} + 14.7)(6.895 \times 10^3)$
Pa	psia	$P_{pa} = (P_{psia})(6.895 \times 10^3)$
Pa	iwg (39.2 °F)	$P_{pa} = (P_{iwg})(249.1)$
MW	10^6 Btu/hr	0.293
MW	GJ/hr	0.278

*These conversions depend on fuel composition. The values given are for typical fuels.

To Obtain ng/J of	Multiply* Concentration in ppm @ 3% O_2 by
Natural Gas Fuel	
CO	0.310
HC	0.177
NO or NO_x (as NO_2)	0.510
SO_2 or SO_x	0.709
Oil Fuel	
CO	0.341
HC	0.195
NO or NO_x (as NO_2)	0.561
SO_2 or SO_x	0.780
Coal Fuel	
CO	0.372
HC	0.213
NO or NO_x (as NO_2)	0.611
SO_2 or SO_x	0.850

APPENDIX B

Form Letter Used For First Contacts

Appendix B
Form Letter for
First Contact

integrated energy systems

Our firm is presently under contract to the U.S. Environmental Protection Agency, to conduct a survey of European experience and current activities with air pollution from wood combustion. The EPA project officer is Mr. M. Osborne.

Our environmental engineer, Werner Martin, dipl Ing ETH, is currently working in Switzerland and intends to travel to visit wood energy experts in January 1981. He will be visiting various institutions, industries, and manufacturers in Scandanavia, Federal Republic of Germany, France, Switzerland, and Austria. We would be most grateful if you could meet with Mr. Martin to show him your work, provide him with your relevant reports, and discuss your planned activiites. Of course you will be given credit for the information in the published report.

An outline of the final report is enclosed. The survey covers all sizes of wood combustion equipment, emission measurements and control techniques, and environmental impacts of wood combustion.

Please return the enclosed post card to Mr. Martin indicating the following:

1. general time available in January 1981;
2. types of sites and information available;
3. permission to take photographs; and,
4. phone numbers when you can be reached.

Mr. Martin will contact you in late December or early January.

Thank you for your cooperation.

Sincerely,

Daniel R. Koenigshofer

Daniel R. Koenigshofer, P.E.
President

301 North Columbia Street • Chapel Hill, North Carolina 27514 • (919) 942-2007

APPENDIX C

Information Resource List and Summary of European Trip

SUMMARY OF EUROPEAN TRIP

DATE	PLACES VISITED	INFORMATION OBTAINED	REMARKS
12/2/80	National Energy Conservation Campaign Manager Dr. K.H. Troxler Zurich, Switzerland	Project of Swiss Wood Combustion Equipment Manufacturers for a Wood Heating Information Center	
12/3/80	INAS, Alternative Energy Corporation, Dr. Walter Lentzch & Ch. Gaegauf	Their experience with a wood gasifiers direct combustion system . "Rogo" and other gasifier equipment in Switzerland.	
1/15/81	Swiss Forestry Center, Solothurn Mr. Flury	Technology used in Switzerland, new trends, air pollution aspects related to wood characteristics.	
1/10/81	Foundation for Appropriate Technology and Socio-Ecology, Langenbruck, Swi. Mr. M. Zimmermann	Activities of the Foundation to provide new wood combustion technologies, like gasifiers combined with IC-engine driven heat pumps.	
1/12/81	Institute for Wood Research Prof. H. Schulz, Dr. P. Topf Munich, FRG	Review of institutes activity in wood energy	Obtained proceedings of Wood Energy Seminar, Munich 1977.
1/13/81	Bavarian Environmental Protection Agency Dr. F. Baum Munich, FRG	Discussion of wood as fuel in Bavaria. Present,future trends, special discussion on implimenting emission standards for wood fired equipment; discussion of possible measuring equipment & schemes.	F. Baum has developed the two dimensional scale for solid fuel fired equipment; several publications incl. the two dimensional chart were obtained.
1/14/81	Gerhard Co. Carpentry Shop Manufacturing store & shop furniture Mr. Bauer, Stockdorf	Wood fired hot water heating system; a Mawera-suspension burner 1GJ/hr capacity only large settling chamber as air pollution control system.	was claimed to be clean system, but still had visible black smoke.

SUMMARY PAGE 2

DATE	PLACES VISITED	INFORMATION OBTAINED	REMARKS
1/16/81	Federal Material Testing Laboratories Dr. R. Muller, Dubendorf,FRG	visited their combustion lab; discussed emission measurement, standards and variables involved.	
1/19/81	Koehler-Bosshard, Inc. Mr. Wind. Basel, Switzerland	discussed their equipment-stoker retort wood burner, air pollution problems in general	supplies more than 50% of larger installations in Switzerland.
1/20/81	VDI (German Assoc. of Engineers) Dr. Lenz Dr. Werner Duesseldorf, FRG	presentation of new draft of VDI Guideline 2300 "Emission reduction for Solid Fuel Fired Steam Generators".	Proceedings of Polycyclic Aromatics as Pollutants Seminar, 1979; Draft of VDI 2300
1/21/81	Frau enhofer Institute for Wood Research Dr. R. Marutsky, Braunschweig, FRG	will start and emission testing of wood stoves sponsored by Fed. Agency for Environmental Prot., Bonn; had a large amount of emission data reports on gasifiers.	
1/22/81	Chimney Sweep Federation of Germ. Mr. Hornborstel Hannover, FRG	explaination on law enforcement responsibilities of chimney sweeps; saw equipment and procedures used.	
1/22/81	TUV Hannover (Technical Surveillance Inst.) Mr. Kotlarski	discussion of various equipment designs and their emissions, policy options	
1/23/81	LIS (Air Quality Inst. of North-Rhine, Westphalia) M. Gliwa	as supervising institute over air quality and air pollution emissions LIS was presenting their data and knowledge about air pollution from wood burners.	it is felt that they have good expertise to tackle emission testing and air quality monitoring problems
1/23/81	Nolting, Inc. Mr. Maertens	visited their production installation; they have test stand with various new types of equipment; medium size grate, and sub suspension burner are their major product. discussion about German emission standards.	

SUMMARY PAGE 3

DATE	PLACES VISITED	INFORMATION OBTAINED	REMARKS
1/26/81	Swedish Environmental Protection Board Folke Larsson, Birgitta Timm Sten Ake Carlsson	review of emissions from wood burners; overview of research activities past, ongoing and in the future	
1/26/81	National Swedish Board For Energy Source Development Britt Sahlestroem Krista, Sweden	overview of Boards activity good documents on wood resources and good contacts to manufacturers of advanced equipment.	
1/27/81	Vaexjoe Energiverk AB (public utility) Ingemar Wensfelt Vaexjoe, Sweden	visit a 30MW district heating plant using a cyclone wood waste burner, electrostatic precipitator reaching very high efficiency and low emissions.	
1/27/81	Flakt, Industrial Group, Sven-Olef Rosby Lennont Erlesand, Vaexjoe	visit at Flakt headquat. technical discussions about cyclone electro-static and fabric filter air pollution control equipment.	Largest Swedish air pollution control equip-ment manufacturer
1/29/81	FDBR (Steam Boiler,Con-tainer and piping Manufacturers Assoc) Dr. Rosahl Dusseldorf, FRG	discussion about new VDI Guidlines: discussed results FDBR emission survey of 6 installations 3-10 MW.	
1/30/81	Weiss. Ltd. Mr. F. Peters H..Pfeiffer Dillenburg, FRG	visited their manufacturing plant: various firing sys-tems from 1 GJ- 144 GJ; new equipment with low emission have been intro-duced in last two years.	

CONTACTS BY TELEPHONE (not including call made to set up meetings)

DATE	PLACES CONTACTED ONLY BY PHONE	INFORMATION OBTAINED	REMARKS
12/21/81	Federal Agency for Environmental Protect. Dr. Wagen knecht Bonn, FRG	gave summery of research activities in FRG in the area of emissions from wood burners; made many suggestions who to contact	
1/12/81	Mr. H, Dionys Consulting Eng.	he designed wood fired cogeneration plant for particle-board plant	site visit was not possible because of plant being temporarily shut down
1/13/81	Erwin Elbel,KG Electro-physics lab Munich, FRG	under contract with Bavaria EPA , they develop a continuous automatic soot measurement instrument with an alarm system.	Mr. Elbel thinks even two dimensional chart would not work for wood fired equipment.
1/14/81	Gewerbeaufsichtsamt (Industrial Hyg Agency) Mr. Kollmann	they do some sporadic measurements in and around industries, but were not able to release data; ref. to TUV Hannover	
1/15/81	VDMA, Assoc of German Machinery & Equipment Manufacturers Mr. Lorenz Frankfurt, FRG	gave an overview of the manufacturers problems to make more efficient cleaner equipment; suggested what manufacturers to visit.	
1/20/81	Swedish Environmental Protection Board Folke Larsson	to check if a one or two day visit in Stockholm; gave address to Kopenhagen contact.	
1/23/81	Danish Boiler Owner Assoc. M. Leif Hansen Mr. Kroiholdt	too busy to meet but would be willing to send some information	

APPENDIX D

Manufacturers List

Appendix D

Manufacturers List

1. AB CTC, Box 135, Ljungby, Sweden
2. Hoval Herzog AG, 8706 Feldmeilen, Switzerland
3. Fuego Biowatt, Zollikerstr. 228, 8008, Zurich, Switzerland
4. Ing. Nolting, 4930 Detmold, Fed. Rep. of Germany
5. "Zima", W. Zirngibl, GmbH, 7590 Achern, Fed. Rep. of Germany
6. Gebr. Weiss, P.O. Box 660, 6340 Dillenburg, Fed. Rep. of Germany
7. Koehler-Bosshardt AG, 4016 Basel, Switzerland
8. Schmid AG, 8360 Eschlikon, Switzerland
9. Goetaverken Angtekmik AB, Kallhaell, Sweden
10. Konus-Kessel, Robert Bosch Str., 6830 Schwetzingen, Fed. Rep. of Germany
11. A. Lambion, Maschinefabrik, 35-40 Arolsen-Wetterburg, Fed. Rep. of Germany
12. Imbert Energietechnik GmbH, 5354 Weilerswict, Fed. Rep. of Germany
13. Etablissements Duvant Valenciennes, Valence, France
14. Borgstroems Platslageri AB, 82300 Kilafars, Sweden
15. Burkhart AG, Konstanzerstr. 8780 Kreuzlingen, Switzerland
16. Ahlstroem, Karhula, Finland
17. Buderus AG, Postfach 1220, 6330 Werzlar, Fed. Rep. of Germany
18. Rogo, 6900 Lugano-Cassarate, Switzerland
19. Tiba AG, 4416 Bubendorf, Switzerland
20. Etienne AG, Horwerstr. 132, 6002 Luzern, Switzerland

21. Roth, Thalopat AG, Feldstrasse 51, 8400 Winterthur, Switzerland

22. Tarm AB, Koepenhagen, Denmark

APPENDIX E

List of Regulations

LIST OF REGULATIONS

Federal Republic of Germany

- Eighth Ordinance for the Implementation of the Air Pollution and Noise Prevention Act of Northrhine-Westphalia, Emission Standards for Solid Fuel Combustion Equipment, Gesetz-und Verodnungsblatt, No. 24/24, March 16, 1970.

- First Ordinance for the Implementation of the Federal Air Pollution and Noise Prevention Act, Emissions Standards for Combustion Equipment, Bonn, October 1, 1974, new version: February 5, 1979.

- VDI Guideline 2300, Final Draft, Emissions Reduction for Steam Generators with Solid Fuel Grate Firing, Dusseldorf, August 1980.

- Energy Conservation Act, Regulation about Requirements for Heating and Domestic Hot Water Systems, Bonn, September 22, 1978.

Switzerland

- Guidelines to Regulations by the Fire-Police, Fire-Prevention Regulation, Assoc. of Cantonal Fire Insurances, Bern, April 1969, revised 1972.

- Advisory Office for Wood Combustion, Guidelines for the Issuance of Certificates, Solothurn, June 1966.

- Federal Guideline for Emission Restriction from Incinerators with Capacities of more than 750 kg/hr, Federal Office for Environmental Protection, Bern, 1980.

Sweden

- Environmental Protection Act and the Environment Protection Ordinance 1969, National Swedish Environmental Protection Board, Stockholm.

- The Building Act, 1974 and Building Statute, 1959, National Board of Urban Planning, Stockholm.